



Inception Report

DemoUp CARMA

Work Package 5. Addressing policy, regulatory, and acceptance challenges to enable CCS deployment

Task 1. Emissions accounting, reporting tools and climate finance mechanisms of negative emissions for national and trans-national CCS solutions

October 2022

Details

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Table of Contents

1. Introduction	5
1.1 Subtask 1.1 Stocktaking, mapping and strategy development	6
1.2 Subtask 1.2 Methodology development under the CCS+ Initiative	6
1.3 Subtask 1.3 Blueprints for climate finance transactions	6
2. Overview of deliverables	7
3. Timelines	8
4. Approach and methodology	9
4.1 Subtask 1.1 Stocktaking, mapping and strategy development	9
4.1.1 Stocktaking exercise	9
4.1.2 Climate finance landscape assessment	9
4.1.3 Climate finance strategy development for CCS	10
4.2 Subtask 1.2 Methodology and toolsets for climate finance transactions	10
4.3 Subtask 1.3 Blueprints for climate finance transactions	10
4.3.1 Swiss compensation scheme blueprint	11
4.3.2 Bilateral international collaboration blueprint	11
4.3.3 Voluntary carbon market blueprint	11
5. Summary of results to date and next steps	12
5.1 Subtask 1.1 Stocktaking, mapping and strategy development	12
5.1.1 Stocktaking exercise	12
5.1.2 Climate finance landscape assessment	13
5.1.3 Climate finance strategy development for CCS	13
5.2 Subtask 1.2 Methodology development under the CCS+ Initiative	13
5.3 Subtask 1.3 Blueprints for climate finance transactions	14

List of tables

Table 1: Overview of deliverables	7
Table 2: Update on deliverables.....	12
Table 3: Anticipated publication dates of CCS+ developed methodology modules	14

List of figures

Figure 1: Objectives of Work Package 5 and Task 1	5
Figure 2: Overview of delivery timelines	Error! Bookmark not defined.

Acronyms and abbreviations

BAFU	Federal Office for the Environment
BFE	Swiss Federal Office for Energy
CCS	Carbon capture and storage (includes CCTS and CCUS)
CCTS	Carbon capture transport and storage
CCUS	Carbon capture utilisation and storage
CDM	Clean Development Mechanism
CDR	Carbon Dioxide Removal
CER	Certified emission reduction
CRCM	Carbon Removal Certification Mechanism
DACCS	Direct air carbon capture and storage
EU ETS	European Union Emission Trading System
FOEN	Federal Office for the Environment
GHG	Greenhouse gas
KliK	Foundation for Climate Protection and Carbon Offset
MRV	Measurement, reporting and verification
SFOE	Swiss Federal Office for Energy
UNFCCC	United Nations Framework Convention on Climate Change
VCM	Voluntary carbon market
VCS	Verified Carbon Standard
WP	Work package

1. Introduction

Negative emissions are an integral component to reduce Switzerland's greenhouse gas emissions by 2050 to net zero, and to reach the country's climate goals. DemoUpCARMA (Demonstration and Upscaling of CARbon dioxide MANagement solutions for a net zero Switzerland) is a pilot project lead by ETH Zurich and funded and supported by the Swiss Federal Office of Energy (SFOE) and the Federal Office for the Environment (FOEN).

DemoUpCARMA aims to demonstrate the implementation and scale up of pathways leading to negative emissions, assessing their optimal design and their upscaling potential considering technological, economical, regulatory, political, and societal factors in the mid- to long-term.

The project is split into five work packages which are subdivided into multiple tasks. The scope of this report covers the work being delivered by South Pole (in collaboration with Perspectives Climate Group) under Task 1 of Work Package 5 (Figure 1 below and overleaf).

Figure 1: Objectives of Work Package 5 and Task 1

Work Package 5. Addressing policy, regulatory and acceptance challenges to enable CCUS and CCTS deployment

- Analyse effective policy designs to ensure public acceptance, mobilise financial investment and guarantee economic viability of CCUS and CCTS solutions.
- Provide to policymakers a portfolio of policy pathways to incentivise the wide adoption of CCUS and CCTS technologies for the decarbonisation of the Swiss economy in line with the findings of the Energy Perspectives 2050+ and towards Switzerland's net zero target by 2050.
- Provide effective and consistent monitoring, accounting and allocation, and reporting tools for CO₂ emissions along CCUS and CCTS value chains.
- Assess potential mechanisms to create and monetise emission reductions and removals generated through the utilisation and storage of CO₂ domestically or abroad.
- Development of blueprints for carbon credit and climate finance transactions to scale up the deployment of CCUS and CCTS solutions.
- Understand financing needs for CCUS/CCTS and how different support policies can overcome their financing challenges (in Switzerland and beyond).
- Understand public and stakeholder support for/opposition to storing or utilising emissions abroad vs. domestically.
- Understand how different support policies will influence public acceptance of CCUS and CCTS.
- Identify gaps and potential solutions with respect to legal and regulatory frameworks relevant to CO₂ capture, national and trans-national transport, utilisation and storage (e.g., long-term liability).
- Provide to relevant bodies and experts a comparative assessment of regulatory pathways to enable and facilitate the development of CCUS and CCTS chains.

Task 1: Emissions accounting, reporting tools and climate finance mechanisms of negative emissions for national and trans-national CCUS and CCTS solutions

The objective of this task is to identify promising climate finance instruments at domestic and international level for implementation and upscaling of CCTS and CCUS value chains, including but not limited to crediting mechanisms. Following a stocktaking and mapping

exercise to identify possible climate finance strategies based on the Swiss CO₂ law, international best practices and other relevant policies, this task will assess in more detail the technical, regulatory and financial feasibility of concrete climate finance options for the CCTS and CCUS activities covered by the DemoUpCARMA project.

(Source: the authors)

The objectives of Work Package 5 and Task 1 will be achieved through the implementation of four subtasks, three of which are carried out by South Pole and Perspectives and covered within the scope of this report.

1.1 Subtask 1.1 Stocktaking, mapping and strategy development

Identifying promising climate finance instruments will be partly achieved by engaging key stakeholders in Switzerland, notably BFE, BAFU, the KliK Foundation, industry partners involved and outside of this project.

A core element of this subtask is a landscape assessment of existing and emerging climate finance instruments in Switzerland and abroad. This assessment will cover political and regulatory mechanisms such as the EU ETS, the 45Q scheme in the United States, voluntary carbon markets, EU sustainable finance taxonomy and various European countries' CDR plans. A critical analysis of the current landscape will then result in the identification of gaps, challenges and opportunities.

Finally, the last step of this subtask will focus on developing a case-specific feasibility assessment and strategy papers discussing possible CCS value chain development strategies for Switzerland.

1.2 Subtask 1.2 Methodology development under the CCS+ Initiative

The objective of this subtask is the development of necessary technical tools for quantifying emission removals and reductions. These methodologies will include detailed insight into the technicalities of potential projects, establish project boundaries, set baselines, assess additionality and ultimately quantify the GHG emissions that will be reduced or removed by a specific project.

A wide range of methodologies covering technologies from the capture, transport, usage and storage part of these value chains are currently developed under the CCS+ Initiative. Furthermore, complementary market toolsets will address specific requirements of climate finance instruments and provide guidance regarding the different implementation processes under, for example, the VCM, the Swiss compliance scheme or Article 6 of the Paris Agreement.

1.3 Subtask 1.3 Blueprints for climate finance transactions

This subtask builds on the previous subtasks with the aim to develop actionable blueprints for climate finance and carbon credit transactions that can help scale domestic and cross-border CCUS or CCTS value chains for CDR. Based on the insights and data gathered across all WPs of the project (including WP2, 3, 4 and 5), this subtask will develop blueprints centred around concrete CCS activities covered in WPs 2, 3 and 4.

The three blueprints to be developed will focus on: (a) a project or programme under the Swiss compensation scheme based on CO₂ capture utilisation and storage in Switzerland, (b) collaboration between an entity domiciled in Switzerland capturing CO₂ and an entity abroad storing the carbon, and (c) domestic and/or cross-border CDR voluntary carbon market transactions (including corresponding adjustments under Article 6 of the Paris Agreement).

Section 2 of this report provides an overview of the deliverables under each subtask. Section 3 presents the timelines for delivery. Section 4 discusses the approach and methodology used to deliver each subtask. Finally, Section 5 summarises the main results achieved to date.

2. Overview of deliverables

Table 1: Overview of deliverables

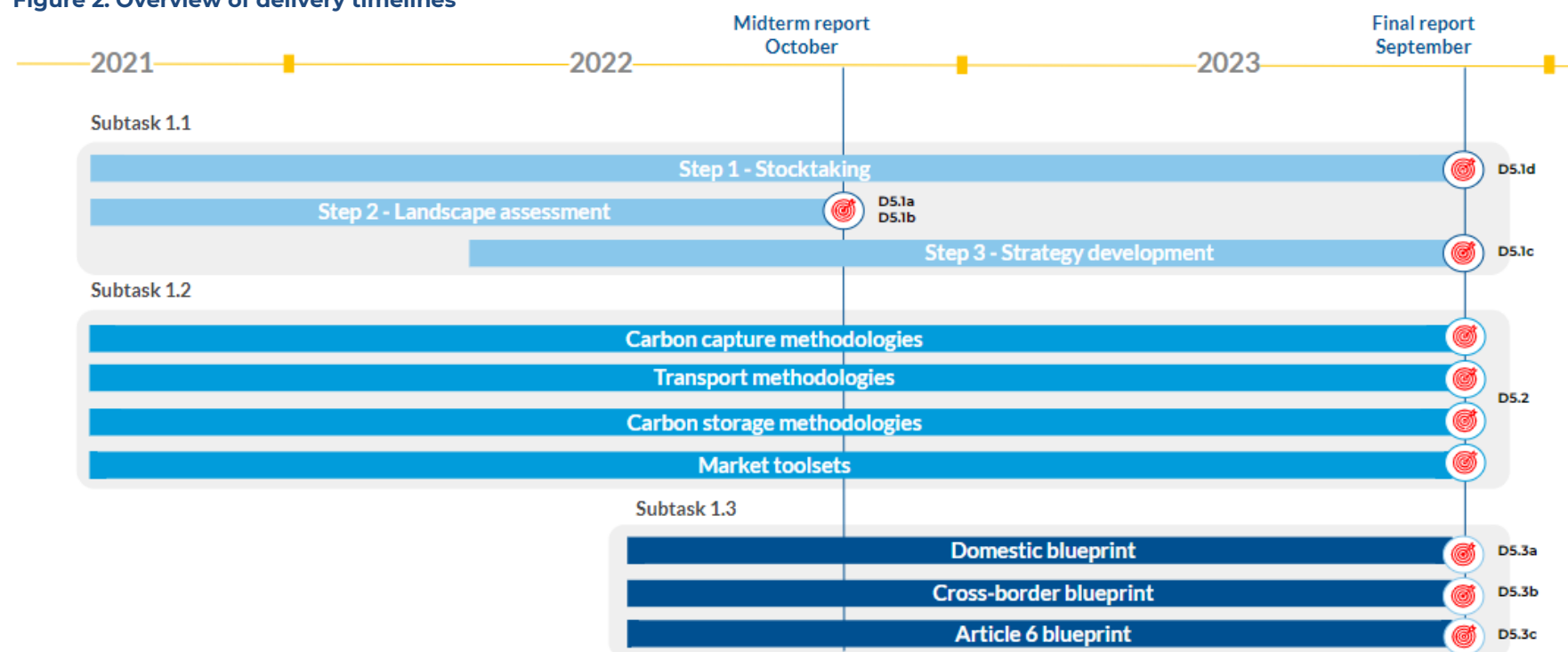
Deliverable	Description
D5.1 (Subtask 1.1)	Landscape assessment and climate finance strategy report, including: a) Inception report with updated objectives and work plan of WP5 Task 1 b) Briefing note on relevant approaches, similar activities in other countries, best practices and identified gaps c) Case specific feasibility assessments and strategy papers d) Documentation of webinars, workshops, events
D5.2 (Subtask 1.2)	Report on fully developed modular baseline and monitoring methodology, including the capture, transport and storage modules necessary for at least two concrete programmes/projects, including capture from CO ₂ at wastewater treatment and waste incineration plants in Switzerland and storage via Carbfix in Iceland or Northern Lights in Norway
D5.3 (Subtask 1.3)	Series of blueprints for concrete climate finance transactions, including following preliminary candidates: a) Blueprint for a programme under the Swiss compensation scheme based on CO ₂ capture from waste incineration plants, followed by (utilisation) and storage in Switzerland b) Blueprint for a collaboration between an entity (domiciled) in Switzerland capturing CO ₂ and an entity abroad storing the carbon (outside baseline and crediting mechanisms) c) Blueprint for a domestic and/or cross-border CDR voluntary carbon market transaction (including corresponding adjustments under Article 6 of the Paris Agreement)

(Source: the authors)

3. Timelines

Figure 2 presents an overview of the timelines associated with each subtask and the expected conclusion of each deliverable. However, it is worth noting that the development of D5.2 is being led by the CCS+ Initiative and the modules will only be deliverable once they become public, which might happen later than September 2023¹.

Figure 2: Overview of delivery timelines



(Source: the author)

¹ This matter is being covered in discussions with ETH Zurich, BAFU and BFE during project implementation.

4. Approach and methodology

4.1 Subtask 1.1 Stocktaking, mapping and strategy development

The overall objective of subtask 1.1 is to identify emissions accounting and reporting tools, promising climate finance instruments and possible implementation strategies for industry and regulators regarding negative emissions – including national and international CCUS and CCTS solutions. This will be achieved through three steps:

- Step 1: stocktaking exercise
- Step 2: climate finance landscape assessment
- Step 3: climate finance strategy development for CCS

The preparation of this inception report (**D5.1a**) is also part of subtask 1.1.

4.1.1 Stocktaking exercise

Under this step, information exchanges and meetings with industry partners and regulators in Switzerland will take place aiming at identifying barriers, challenges and opportunities to better assess feasible solutions for the overarching goal of WP5. If needed, industry players and regulators abroad may be consulted to broaden the scope of discussions around possible solutions and their adaptability to Switzerland.

The stocktaking exercise will be a continuous ongoing step that will last for the whole duration of the project. Upon the completion of the DemoUpCARMA project, full documentation of the conducted questionnaires, meetings, workshops and interviews with stakeholders will be delivered (**D5.1d**).

4.1.2 Climate finance landscape assessment

The Government of Switzerland has assigned CCTS and CCUS crucial roles in its long-term strategy of reaching net zero GHG emissions by mid-century. Switzerland's net zero GHG emissions pledge is supported by the 'Energieperspektiven 2050+' strategy of the Swiss Federal Office of Energy, which aims to achieve 11.7 million tCO₂ of emissions reductions and removals through CCS and negative emission technologies by 2050 (Bundesamt für Energie, 2020).

Most of the technologies to enable the Government of Switzerland to achieve this goal, however, do not currently have a viable business case, due to their associated high costs and insufficient returns on investment. To become economically viable, these technologies will require further economic incentives (e.g. carbon revenues, subsidies and innovation grants).

The result of this step will be deliverable **D5.1b** – a briefing note examining various existing and possible future sources, both in Switzerland and other jurisdictions, for such economic incentives and critically discussing their prospect for mobilising and scaling CCS-based mitigation methods.

The briefing note takes stock of, and maps, possible climate finance strategies based on domestic instruments (including the Swiss CO₂ law) and international best practices, such as targeted subsidies and carbon pricing instruments. It offers an overview for practitioners (industry) and decision makers (policymakers) of the relevant Swiss policies for accounting and financing CCS (Section 2 of the briefing note) and of the international landscape of existing and emerging incentives potentially applicable to CCS (Section 3 of the briefing note). Based on this mapping, the briefing note then discusses the key gaps in the present landscape and potential solutions to close these gaps (Section 4 of the briefing note).

4.1.3 Climate finance strategy development for CCS

Under Step 3, the development of strategy papers (**D5.1c**) outlining a range of approaches towards strengthening the business case of CCS activities will follow the conclusion of the climate landscape assessment. The gaps, challenges and opportunities identified in Step 2 and the engagement undertaken in Step 1 will inform the development of suitable strategies covering the different applications of the CCS value chain that addresses the role to be played by the different stakeholders (e.g. industry, regulators).

The strategy papers will cover: (i) key success factors for the potential implementation of climate finance solutions, (ii) most promising climate finance approaches applicable to the Swiss context, (iii) relevant aspects regarding the accounting, eligibility and feasibility of CDR activities, and (iv) strategic considerations for industry partners as well as policymakers and regulators on their role to promote effective climate finance approaches to scale up CCS activities.

4.2 Subtask 1.2 Methodology and toolsets for climate finance transactions

The development of MRV methodologies and accompanying guidance tools (**D5.2**) will follow the institutional processes of the standard setter. DemoUpCARMA benefits from work conducted under the CCS+ Initiative, which is developing a broad suite of MRV methodologies and accompanying guidance tools for mitigation activities involving CCTS under the Verified Carbon Standard (VCS) by Verra. Given that the processes of Verra – including public consultation periods – have to be followed, the methodologies will become available once the window for public consultation is opened. Table 3, in Section 5, provides an update on the anticipated publication dates of CCS+ developed methodology modules for the VCS of relevance to CCUS and CCTS activities.

4.3 Subtask 1.3 Blueprints for climate finance transactions

This subtask builds on the previous subtasks to develop actionable blueprints (**D5.3**) for climate finance and carbon credit transactions that can enable and scale domestic and cross-border CCUS or CCTS value chains. Beyond the challenges and avenues for action identified within previous subtasks, the development of blueprints will also draw on insights and data gathered across other WPs of the project.

The blueprints will consist of concrete stepwise explanation of a possible approach to mobilising carbon revenue for concrete CCS activities covered in WPs 2, 3 and 4 – i.e. capture of biogenic CO₂ from wastewater treatment, waste incineration or industrial plants followed by CO₂ storage through mineralisation in demolished concrete in Switzerland, basaltic rock formations in Iceland (via Carbfix) or sub-seabed storage in underground aquifers in Norway (via Northern Lights).

The blueprints will be similar to a Project Design Document (PDD), and will include information on specific project activities which are likely to be restricted – hence these deliverables will be confidential documents. A simplified conceptual document that can become public can potentially be prepared to raise awareness towards opportunities to secure climate finance in the CCS space.

The suggested structure for each blueprint will include:

1. Short project or programme design description (covering the demonstration phase and beyond)
2. Summary of technical feasibility (based on work conducted under WPs 2, 3 and 4)
3. Policy assessment and regulatory feasibility (based on WP5, subtask 1.1 and Task 5.2)
4. Calculation of ex-ante baseline, project and leakage emissions for each project or programme based on the methodology developed under WP5, subtask 1.2
5. Financial assessment (based on inputs from WPs 2, 3 and 4) and recommended climate finance strategy for each project or programme (based on WP5, subtask 1.1 and Task 5.2), including an in-depth assessment of the financial needs of each project or

programme on how the climate finance component would be embedded in the overall financial structure of the project/programme

6. Assessment of additionality as per requirements of the targeted climate finance instrument (and guidance developed under WP5, subtask 1.2)
7. Definition of a Measurement, Reporting and Verification (MRV) approach, including a detailed monitoring plan and quality assurance processes that will deliver the data for the ex-post measurement, reporting and verification of emission reductions/removals (based on the methodology modules developed under WP5, subtask 1.2)
8. Definition of carbon accounting practices (i.e. at the national or international level) and units that may be claimed (by whom) as part of the climate finance transaction (based on guidance provided by the complementary toolsets developed under WP5, subtask 1.2)
9. Assessment of wider environmental and social impacts of each project/programme as per requirements of the targeted climate finance market instrument, including an assessment of public acceptance (based on WP5, Task 5.2)
10. Recommended next steps towards implementation of each blueprint, including a gap assessment and respective mitigation plans (if applicable) and the possible implementation of pilot climate finance transactions

The aim of the blueprints would be to design and thus facilitate climate finance commitments, which would provide sufficiently long-term carbon revenue certainty for CCUS and CCTS projects in Switzerland. Nevertheless, some of the targeted activities and market instruments (for example, the domestic CO₂ compensation scheme operated by KliK, international transactions under Article 6.4 or 6.2 of the Paris Agreement or voluntary carbon markets) may face regulatory or administrative barriers that can hold back implementation. In this case, subtask 1.3 will develop guidance and propose solutions to relevant policymakers, regulators and standard bodies to address the identified barriers towards implementation. This subtask will draw on input from relevant industry partners, based on their needs and exposure to emerging markets for CCS-based mitigation activities involving underground permanent storage.

4.3.1 Swiss compensation scheme blueprint

The first blueprint (**D5.3a**) will address a project or a programme under the Swiss compensation scheme based on CO₂ capture utilisation and storage in Switzerland. The specific BAFU requirements for registration of projects and programmes under the Swiss compensation schemes will be followed. Therefore, the concrete structure of this blueprint will be closely discussed with BAFU and KliK, to produce a suitable outcome for project and programme implementation.

4.3.2 Bilateral international collaboration blueprint

The second blueprint (**D5.3b**) will address a potential collaboration between an entity domiciled in Switzerland capturing CO₂ and an entity abroad storing the carbon (outside baseline and crediting mechanisms). Among other issues, this blueprint will examine the legal basis, the particular regulatory challenges and the accounting and claims associated with the mitigation results. This blueprint will draw on the unpublished legal analysis of transboundary CDR activities commissioned by FOEN and delivered by Perspectives.

4.3.3 Voluntary carbon market blueprint

The third blueprint (**D5.3c**) will address possible domestic and/or cross-border CDR voluntary carbon market transactions (including corresponding adjustments under Article 6 of the Paris Agreement). Given the high degree of advancement of the Verified Carbon Standard (VCS), this blueprint will focus strongly on mobilising the different elements of the ecosystem of tools developed under the VCS and by the CCS+ Initiative, including guidance for developing projects under the VCS toward compatibility with the EU ETS, Article 6, and potentially the CRCM in the future (should relevant activity types become eligible).

5. Summary of results to date and next steps

Table 2: Update on deliverables

Deliverable	Update
D5.1	a) Inception report – Delivered b) Briefing note – Delivered c) Case specific feasibility assessments and strategy papers – due by September 2023 d) Documentation of webinars, workshops, events – due by September 2023
D5.2	Methodology modules - due by September 2023
D5.3	Series of blueprints for concrete climate finance transactions – due by September 2023

(Source: the authors)

5.1 Subtask 1.1 Stocktaking, mapping and strategy development

5.1.1 Stocktaking exercise

A first engagement with stakeholders has been conducted via a questionnaire addressing general but also subtask-specific questions, providing an initial overview of perspectives on CCTS and CCUS. Joined workshops, interviews and/or discussions with members of other corresponding work packages and specific stakeholders are planned to take place in 2023. The results coming out of these consultations will point out expectations and necessities for the development, financing and regulatory instrument regarding CCTS and CCUS value chains.

As a first information collection, a set of questionnaires were sent out to industry partners and regulations contributing to the DemoUpCARMA project. The preliminary findings and main conclusions from this consultation are summarised in Figure 2 (overleaf). Members of WP5 set up questionnaires for stakeholders of the project to gain a first understanding of the general state of the art on knowledge regarding CCUS and CCTS. All members (research and consultant partners exempt) of the project were categorised into regulators, emitters and technology and service providers. Questionnaires directed to the different groups differed slightly due to stakeholder-specific questions. Topics covered in the questionnaire included: general knowledge and approach towards CCUS and CCTS, financial issues and barriers, regulatory hurdles, technical standpoint perspectives, and acceptance and communication matters.

Figure 2: Preliminary findings from the stakeholder questionnaires

- General understanding of CCUS and CCTS is highest among the regulators, followed by emitters. Tech and service providers tend to be quite knowledgeable in their respective aspect of the CCTS/CCUS value chain.
- Regarding the financials and regulations, stakeholders were quite clear that they envision a market-based approach to finance CCUS and CCTS to be more effective than a command-and-control approach. However, with no precise and clear regulations, many uncertainties regarding risk assessments and carbon price stability prevent fundamental investments in CCS infrastructure.
- Technical availability of capturing CO₂ is quite advanced, but the large uncertainties associated with transportation and storage capacities hinder actors' willingness to proactively emerge as early movers.
- With regards to transportation, the need and current lack of planning for an adequate pipeline infrastructure as the main transportation mode for the CO₂ captured further intensify the feeling of uncertainty mentioned by stakeholders.
- Further uncertainties, like the acceptance of CCS technologies by the general public, are factors that stakeholders consider as non-negligible, and acceptance of CCS closely aligns with the level of knowledge and understanding its necessity in the context of climate change.
- Communication and knowledge building among the general population is key to minimise the doubt in technological feasibility and risks assessment. This is particularly important for Switzerland, as citizens participate in referendums and contribute to decision making regarding important regulatory changes. Hence, an increased technological understanding of CCS solutions by the general Swiss population is seen as important.

(Source: the authors)

5.1.2 Climate finance landscape assessment

The briefing note is being delivered together with this inception report and the midterm report, it offers an overview of the relevant Swiss policies for accounting and financing CCS, and of the international landscape of existing and emerging incentives potentially applicable to CCS. The gaps and challenges associated with financing CCS and promoting its scale-up are discussed, as well as opportunities to address them.

5.1.3 Climate finance strategy development for CCS

The development of the strategy papers will follow the conclusion of the climate landscape assessment. A discussion between the project team, BAFU and BFE to address the approach for the development of the strategy paper and ensure they are aligned with BAFU/BFE's priorities and strategy is scheduled for 18 October 2022.

5.2 Subtask 1.2 Methodology development under the CCS+ Initiative

The CCS+ Initiative has been leading this subtask and has continuously been making progress on the development of the methodologies. Table 3 (overleaf) provides an update on the likely delivery date for each methodology.

Table 3: Anticipated publication dates of CCS+ developed methodology modules

Methodology	Anticipated delivery date
Baseline & monitoring methodology – CO₂ capture modules	
Carbon capture from power and heat – CO ₂ capture from wastewater treatment plants	01/2023
Carbon capture from power and heat – CO ₂ capture from solid waste incineration plants	01/2023
Carbon capture from industrial processes – CO ₂ capture from industry point source emissions	01/2023
Carbon capture from air	01/2023
Baseline & monitoring methodology – Consolidated CO₂ transport	
CO ₂ transport by road	01/2023
CO ₂ transport by rail	01/2023
CO ₂ transport by barge and ship	01/2023
CO ₂ transport by pipeline	01/2023
Baseline & monitoring methodology – CO₂ storage modules	
Geological carbon storage – in saline aquifers and depleted oil and gas reservoirs	01/2023
Geological carbon storage – in igneous rock formations	10/2023
CO ₂ mineralisation in concrete production for ready mix and precast	12/2023
Additional toolsets for specific market and standard requirements	
Compliance guidance for Article 6 transactions	01/2023
Compliance guidance for voluntary carbon markets	04/2023

(Source: the authors)

5.3 Subtask 1.3 Blueprints for climate finance transactions

No relevant progress has been made yet on the development of the blueprints. Upon delivery of the midterm report, the team will digest the work undertaken under Work Packages 2, 3 and 4 and begin working on subtask 1.3.



Briefing Note

Climate finance landscape assessment

DemoUp CARMA

Work Package 5. Addressing policy, regulatory, and acceptance challenges to enable CCS deployment

Task 1. Emissions accounting, reporting tools and climate finance mechanisms of negative emissions for national and trans-national CCS solutions

October 2022

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Table of Contents

Executive summary	6
1.	9
2.	10
2.1.	10
2.2.	11
2.3.	12
2.4.	13
3.	16
3.1.	16
3.1.1.	16
3.1.2.	17
3.2.	18
3.2.1.	18
3.2.2.	19
3.3.	19
4.	24
5.	29
5.1.	29
5.2.	29
5.3.	31
6.	35

Table 1: Requirements for compensation projects involving carbon storage	18
Table 2: Overview of selected public policy instruments	24
Table 3: Overview of selected voluntary private sector instruments	28
Table 4: Examples of supply push versus demand pull instruments	29

List of figures

Figure 1: Swiss climate finance instruments supporting CCS	6
Figure 2: Selected international instruments applicable to CCS	6
Figure 3: Selected opportunities for actions to scale the deployment of CCS	7
Figure 4: Types of mitigation policy instruments	10
Figure 5: Investment- and operation-related costs that may require carbon revenues.	15

Acronyms and abbreviations

ACCU	Australian Carbon Credit Units
AMC	Advance market commitments
BECCS	Bioenergy with carbon capture and storage
CCS	Carbon capture and storage (includes CCTS and CCUS)
CCTS	Carbon capture transport and storage
CCUS	Carbon capture utilisation and storage
CDR	Carbon Dioxide Removal
CDM	Clean Development Mechanism
CER	Certified emission reduction
CfD	Contract-for-difference
CRCM	Carbon Removal Certification Mechanism
DAC	Direct air capture
DACCS	Direct air carbon capture and storage
EEA	European Economic Area
ERF	Emission Reduction Fund
EOR	Enhanced oil recovery
EU ETS	European Union Emission Trading System
EGR	Enhanced gas recovery
FOEN	Federal Office for the Environment
GHG	Greenhouse gas
GWP	Global warming potential
ICROA	International Carbon Reduction and Offset Alliance
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change

ITMO	Internationally transferred mitigation outcomes
LCFS	Low Carbon Fuel Standard
LTS-LEDS	Long-term low greenhouse gas emission development strategies
MRV	Measurement, reporting and verification
NDC	Nationally Determined Contribution
NIR	National inventory reports
RDD&D	Research, design, development and demonstration
SFOE	Swiss Federal Office for Energy
UNFCCC	United Nations Framework Convention on Climate Change
VBSA	Swiss Waste Treatment Installations
VC	Venture capital
VCM	Voluntary carbon market

• Executive summary

As governments around the world scale-up their climate change mitigation efforts, the vital roles of CCS in achieving the temperature goal of the Paris Agreement is increasingly being recognised (Global CCS Institute, 2022). While Switzerland has assigned CCS a crucial role in its long-term strategy of reaching net zero GHG emissions by mid-century, most of the technologies required to enable this goal, do not currently have a viable business case due to their associated high costs and insufficient returns on investment. To become economically viable, these technologies will require further economic incentives.

Alongside the crucial role that public actors play in the design of appropriate policy instruments to scale-up CCS (e.g., public mitigation targets, subsidies, grants, carbon pricing), private sector actors have an important role to play by providing additional finance streams (e.g., equity and debt finance, voluntary carbon markets, and offtake agreements).

While several initiatives have been identified in Switzerland and globally to support CCS activities – as highlighted in Figures 1 and 2 –, stronger mechanisms to drive up the demand for CCS globally in the long-term are still to be developed. Some of the key challenges associated with this relate to: (i) the insurance of long-term stability of policy instruments and carbon revenues, (ii) the high investment risks and long pay-back periods associated with CCS projects, and (iii) the need for a coordinated centralised approach at international, national or regional levels for the development of transportation and storage infrastructure and the efficient operation of these activities.

Figure 1: Swiss climate finance instruments supporting CCS

Swiss ETS. The revision of the Swiss CO₂ Ordinance includes CCS towards emissions reductions, as well as towards achieving negative emissions within ETS compliance. The waste sector, however, is not included in the ETS.

Article 6 transactions. Switzerland will explicitly rely on purchasing emission reductions and removals certificates from abroad to reach its NDC. Agreements specifically addressing CCS and CDR have been signed with Iceland and the Netherlands.

Climate Cent Foundation. The Climate Cent Foundation has launched a tender for carbon projects in the areas of negative emission technologies and CCS. The foundation's remaining assets will be used to finance CCS projects in Switzerland and abroad.

Waste sector agreement. A sector agreement for the waste incineration industry with specific CCS targets has recently been signed between the Swiss government and the Verband der Betreiber Schweizerischer Abfallverwertungsanlagen (VBSA).

Swiss Technology Fund. The Technology Fund offers loan guarantees to Swiss companies developing products that contribute to GHG emission reductions. CCS projects are eligible to receive support, though few CCS applications have been submitted so far.

SFOE funding. Since 2021, 'SWEET' has targeted early RDD&D stages contributing to the Swiss Energy Strategy 2050 and the Swiss climate goals. The fund is structured around topical calls, with a call on net zero scheduled for 2024.

Figure 2: Selected international instruments applicable to CCS

EU Carbon Removal Certification Mechanisms (CRCM). The EU Commission has set out to develop a tool for certifying CDR from various activities. This is to strengthen comparability

and credibility as a basis for later including more sectors/activities into the ETS or to enable removals to be sold into the ETS.

EU Innovation Fund. The Innovation Fund is the EU's most important tool for supporting the commercial demonstration of innovative low-carbon technologies. For the period 2020-2030, it will provide EUR 38 billion in funding for low-carbon technologies in energy-intensive industries, CCS projects, energy storage, and innovative renewable energy generation.

EU Connecting Europe Facility. The Facility is a key EU funding instrument promoting growth and competitiveness through targeted infrastructure investment. It seems likely that this facility will be one of several instruments through which the EU seeks to support the development of geological storage sites in anticipation of a more systematic policy approach.

US 45Q tax credit. Section 45Q of the Internal Revenue Code represents a US federal tax credit that applies for carbon dioxide sequestration. It is expected that 45Q will have a similar strong effect as the tax credits that led to the rise in wind and solar power generation.

Sweden's reverse auction approach. The Swedish government announced the procurement of a certain amount of removals via long-term commitments. The private entity with the lowest costs associated with removals would win the auction. Initially scheduled to take place in 2022, the first auction has been postponed until 2023 to ensuring compliance with European state aid rules and further regulations and conditions.

Dutch approach to CfDs. The Netherlands awarded a large-scale CCS project based on a contract-for-difference (CfD) approach originally used for subsidising renewable energy. It offers an operating subsidy equal to the difference between the cost of value chains, including permanent storage and the market price of the alternative products without CCS. While the EU has expressed interest in an European approach for CfDs in the context of the EU ETS, this instrument is also viewed critically and can potentially be linked to short- and long-term distortions in the market.

Voluntary carbon markets. Increasing attention has been given to the scaling of CCS-reliant projects in the voluntary carbon markets. The CCS+ initiative is a notable example of this development, which is expected to play a significant role in bridging voluntary and compliance markets through the development of tools that should aid project developers to comply with the rules of, e.g., the EU ETS and the Article 6.4 mechanism.

Frontier advance market commitment. Frontier is an advance market commitment set up by Stripe, Alphabet, Shopify, Meta, and McKinsey that aims to accelerate the development of CDR by guaranteeing future offtake up to 2030.

As a result of the analysis undertaken within the scope of this landscape assessment, several opportunities have been identified for stakeholders to take action and contribute to addressing existing challenges and scaling the deployment of CCS solutions. A selection of the key opportunities identified is presented in Figure 3

Figure 3: Selected opportunities for actions to scale the deployment of CCS

Development of de-risking instruments and provision of ensured carbon revenues for CCS activities. CfDs are one example of a price guarantee instrument through which the difference between a pre-defined carbon price and the actual allowance price is paid to the project developer. Long-term offtake agreements – a well-tested instrument – can also contribute to the financial viability of CCS projects through the provision of guaranteed returns. The design and implementation of a tax credit instrument for CCS activities, inspired on the successful experience of the 45Q scheme in the United States could significantly contribute to promoting CCS deployment in Switzerland and the EU.

Expansion of initiatives within KliK. The Climate Cent Foundation is currently engaging in long-term emissions reductions purchase agreements at a fixed price to give a sufficient

certainty of investment returns for specific project types. With available funds, KliK could be directed to escalate this approach with a focus on CCS projects.

Coordination for the development of transportation and storage infrastructures.

Governments have an important role to play in (i) contributing to the development of transportation and storage infrastructure, and (ii) regulating transportation and storage activities to ensure fair access and efficient operationalisation. Experience can be leveraged from the market and regulatory structures used for the development and operation of water and energy supply infrastructures.

Modification of the fossil fuel importers' obligations. The existing obligations imposed in Switzerland to importers of fossil fuels could potentially be modified to include a specific carbon removal obligation (e.g., as a fraction of the total compensation obligation).

Improvements to the EU and Swiss ETS. While the Swiss and EU ETSs cover power and heat generation from fossil-thermal power plants (and associated CCS activities), biomass power plants are not covered. A modification of both ETS could allow for the incentivisation of BECCS if biomass-based power plants were included and received free allowances that could be sold to other actors subject to the ETS.

1. Introduction

As governments around the world scale-up their climate change mitigation efforts, policymakers, civil society groups and climate experts are increasingly recognising the vital roles of carbon capture, transport and storage (CCTS) and carbon capture, utilisation and storage (CCUS) in achieving the temperature goal of the Paris Agreement (Global CCS Institute, 2022).

CCTS and CCUS are poised to enable the decarbonisation of, in particular, hard to abate industrial sectors for which greenhouse gas (GHG) emission reduction technologies are currently unfeasible or commercially unviable. Against this backdrop, the number of commercial facilities capturing and storing CO₂ – with or without intermediate use – has grown substantially in recent years (International Energy Agency, n.d.). This has been spurred by favourable policy and regulatory developments, the growth in the number of companies setting net zero GHG emission targets, and cost reductions in CCTS and CCUS technologies (Global CCS Institute, 2021). Indeed, between the end of 2020 and September 2021, the capacity of CCS projects in development grew by 48% (Global CCS Institute, 2021). In 2021, approximately 230 million tCO₂ were captured and used primarily for either the manufacture of urea or enhanced oil recovery (International Energy Agency, n.d.).

For its part, the Government of Switzerland has assigned CCTS and CCUS crucial roles in its long-term strategy of reaching net zero GHG emissions by mid-century. Switzerland's net zero GHG emissions pledge is supported by the 'Energieperspektiven 2050+' strategy of the Swiss Federal Office of Energy, which aims to achieve 11.7 million tCO₂ of emissions reductions and removals through CCS and negative emission technologies by 2050 (Bundesamt für Energie, 2020).

Most of the technologies to enable the Government of Switzerland to achieve this goal, however, do not currently have a viable business case due to their associated high costs and insufficient returns on investment. To become economically viable, these technologies will require further economic incentives (e.g., carbon revenues¹, subsidies and innovation grants).

This briefing note examines various existing and possible future sources, both in Switzerland and other jurisdictions, for such economic incentives and critically discusses their prospect for mobilising and scaling CCS-based mitigation methods. The briefing note takes stock of, and maps, possible climate finance strategies based on domestic instruments (including the Swiss CO₂ law) and international best practices, such as targeted subsidies and carbon pricing instruments. It offers an overview for practitioners (industry) and decision-makers (policy-makers) of the relevant Swiss policies for accounting and financing CCS (section 2) and of the international landscape of existing and emerging incentives potentially applicable to CCS (section 3). Based on this mapping, the briefing note then discusses the key gaps in the present landscape and potential solutions to close these gaps (section 4).

¹ Carbon revenue is defined as revenue that accrues for the explicit delivery of mitigation action – results-based for each tonne of CO₂ not emitted or removed.

2. Different types of incentives and their potential role in driving the scale-up of CCS value chains

2.1. Public policy incentives

Linked to the IPCC taxonomy (Gupta et al., 2007), mitigation policy instruments can broadly be distinguished into five types, as presented in Figure 4, ranging from generic international frameworks to targeted support for specific activities on the sub-national level. While most of these instruments have historically been used to promote climate mitigation related to the scaling up of renewable energy capacity or enhancements in energy efficiency, they can also potentially be applied to promote mitigation through CCS value chains.

Figure 4: Types of mitigation policy instruments

Public mitigation targets such as those defined by the Paris Agreement's Parties' Nationally Determined Contributions (NDCs) or long-term low greenhouse gas emission development strategies (LTS-LEDs) ratify government's ambitions to mitigate climate change into a formal commitment, hence incentivising climate mitigation activities.

Regulatory mandates such as emissions standards (e.g., for a specific maximum emissions intensity in energy or industry) or sector agreements have previously been used to drive climate mitigation. A sector agreement for the waste incineration industry with specific CCS targets has recently been signed between the Swiss government and the Verband der Betreiber Schweizerischer Abfallverwertungsanlagen (VBSA).

Subsidies have been a key instrument in mobilising renewable energy generation capacities (e.g., through feed-in tariffs). They can take the form of, e.g., dedicated direct grants, tax credits, concessional loans, contracts-for-difference or reverse auction schemes. Subsidies for research, design, development, and demonstration (RDD&D) are presently used to advance various CCS technologies.

Carbon pricing instruments allow for the creation of results-based incentives. For emissions-reducing measures, carbon taxes and carbon markets have both been effective tools for medium- to long-term incentivisation. Markets include cap and trade systems (such as the EU and Swiss ETS), baseline and credit systems (like the voluntary carbon markets or the Paris Agreements' Article 6) or carbon taxes. While most of the existing instruments allow, in principle, to incentivise CCS, they do not yet provide a sufficiently large and stable revenue for sizeable investments in CCS.

Ancillary policy instruments can include various instruments suited to complement medium- to long-term carbon pricing or regulatory instruments. These can include guarantees (e.g., for long-term storage), harmonised liability rules, de-risking instruments, or public information campaigns.

(Source: the authors, based on Gupta et al., 2007)

Two aspects are especially noteworthy when mapping and examining existing and planned mitigation policy instruments. First, irrespective of the chosen instrument, the appropriateness and efficiency of the instrument to accelerate technological maturity, societal learning and capacity building should be monitored and evaluated continuously. This allows for the transparent tracking of the progress of technological and political developments, to identify remaining finance or regulatory gaps, and redesign the

instrument accordingly if needed to avoid perverse incentives. And second, the possible interplay of different policy instruments should be considered as they can work on their own; in isolation without linkages to other policies; or be designed as individual parts of a broader mix and sequenced to address different stages of technological maturity.

2.2. The potential role of the private sector

Alongside the crucial role that public actors play in the design of appropriate policy instruments to scale-up CCS, private sector actors have an important role to play by providing additional finance streams (e.g., equity and debt finance, voluntary carbon markets, and offtake agreements). Historically, private sector actors have generally shown more interest in purchasing credits that have already been generated through carbon markets instead of investing in the underlying assets and structures for CCS. This is mostly due to the uncertainty and risks associated with the actual carbon credit generation from CCS projects and the lack of robust regulatory frameworks and methodologies targeted at CCS.

However, private sector actors have been increasingly taking action to provide the necessary finance flows to develop CCS technologies and bring them to scale. The First Movers Coalition, for example, is a group of more than 50 companies and ten governments pushing to decarbonise seven hard to abate sectors (aluminium, aviation, chemicals, concrete, shipping, steel, and trucking) and promote innovative carbon removal technologies. Participating companies include Alphabet, Meta, Microsoft, Salesforce, and FedEx, alongside the governments of Denmark, Germany, India, Italy, Japan, Norway, Singapore, Sweden, the United Kingdom, and the US. Companies who join the coalition pledge to contract at least 50 thousand tonnes or USD 25 million of durable and scalable CO₂ removals by 2030. Some participants – Alphabet, Microsoft and Salesforce – have gone beyond these minimum pledges and committed themselves to investing USD 500 million in carbon removal by 2030 (WEF, 2022). The Coalition expects that the investment pledges of its members will lead to tipping points that increase affordability and drive the long-term deployment of low-carbon technologies.

Another example of private sector action is the Frontier fund – an advanced market commitment scheme targeted start-up companies working with carbon removals launched by Stripe, Alphabet, Shopify, Meta, and McKinsey Sustainability. Together these companies have committed to purchase USD 925 billion of carbon removals by 2030. Start-ups can pitch their removal technologies to Frontier, which evaluates these according to permanence, capacity, land use, cost and social-equity criteria. If the idea is accepted, Frontier negotiates a price per tonne and commits to paying for the delivery of the removals, which consequently helps these start-ups secure venture capital funding by being able to showcase a guaranteed market for their products (Bloomberg, 2022).

A significant increase in venture capital (VC) investments is another sign of the rapidly growing interest of the private sector in CCS technologies. Recent data shows that investment in CCS start-ups by VC firms in the first two quarters of 2022 has reached a record USD 882 million across 11 deals. To compare, the two quarters of the previous year saw VC investments in the sector totalling USD 432 million (Pitchbook, 2022).

2.3. Carbon revenue needs in different CCS applications

Different types of CCS applications have different carbon revenue needs on their path to becoming economically viable. Hence, public policy design needs to consider the specific characteristics of each application in terms of revenue needs and market structures.

Bioenergy with carbon capture and storage (BECCS)

At present and for the foreseeable future, energy generation from biomass without CCS is less expensive than BECCS. Given that the energy market is highly competitive, it is unlikely that the cost of embedded CCS can simply be included in the cost of energy and passed to the consumer. Hence, securing additional carbon revenues is necessary to make BECCS installations economically viable in a highly competitive market.

CCS in waste incineration

In contrast, the market for waste disposal services is less competitive. In many cases, it is carried out directly by municipalities or by a provider that has been granted a monopoly (OECD, 2013). Private households and local industries have, in practice, less flexibility in choosing their service providers. Therefore, the additional cost of capturing CO₂ at a waste incineration plant, transporting it to a storage site and paying the site operator for the storage service could more easily be included in the waste-disposal service fee – even if that would mean an increased cost to the consumer.

CCUS and EOR/EGR

CCUS refers to applications in which the captured carbon is either used directly or transformed into another product. It is estimated that 230 MtCO₂ are utilised each year, mostly in the fertiliser industry for urea manufacturing, in the oil and gas industry for enhanced recovery (EOR/EGR), in the food and beverage industry, or the farming industry for yield-enhancing in greenhouses.² While the CCUS can contribute to climate mitigation, particularly when used in products with long carbon retention, the IEA estimates in its Net Zero Scenario that only 5% of all the carbon captured in 2030 will be used, with the rest being geologically stored (IEA, 2022).

Except for the use of carbon in building materials, the potential for most CCUS applications to tap into carbon revenues is quite limited as they do not lead to permanent carbon storage. Some value chains for CCUS in durable products³ may gradually emerge, for example, to produce carbon-enriched concrete or plastics. In these contexts, DAC or BECCS processes could produce and sell climate neutral CO₂, which would stand in direct competition with dedicated CO₂ production. Targeted subsidies or a carbon tax could potentially be implemented to allow captured CO₂ prices to match that of the CO₂ currently produced from fossil sources, hence incentivising CCUS value chains.

While using captured CO₂ in EOR/EGR can result in durable storage of the CO₂, the provision of incentives for this application is a controversial topic. Producing oil and gas

² Through which site operators can inject CO₂ into oil and gas reservoirs and enhance their extraction productivity.

³ Application examples include durable materials that replace plastics or steel or mineralisation of CO₂ in recycling concrete. Short-lifetime products like synthetic and e-fuels carbonated beverages or enhancing plant growth in greenhouses do not result in durable storage.

using enhanced recovery methods and captured CO₂ contributes to mitigation efforts and has played an important role in the technical development of CCS technologies. Certainly, producing oil and gas with EOR/EGR is better than using conventional techniques. However, a complete phase-out of oil and gas production would be required to achieve the Paris Agreement ambitions (IISD, 2022), which creates a risk to the credibility of incentives that support oil and gas production.

In the US, the 45Q tax credit (further detailed in section 3) – for which EOR/EGR operations are eligible – is an example of a successful public policy incentive that currently supports CCS. Indeed, promoting EOR/EGR through similar policy instruments might be effective in contributing to mitigation efforts in the oil and gas sector and the scale-up of CCUS activities, especially in fossil fuel-producing countries. Concerning the carbon markets and the generation of carbon credits from CCUS in EOR/EGR, overcoming the associated reputational risks will be a significant challenge, as even detailed and technically credible evaluations of additionality might not be sufficient.

Direct Air Carbon Capture and Storage (DACCS)

DACCS technologies remove CO₂ directly from the atmosphere and then store it permanently. As the concentration of CO₂ in the air is generally very low, the energy required in this process and the costs associated with it are generally significantly higher if compared to technologies that capture carbon from concentrated sources (e.g., in industrial processes, BECCS, waste incineration). DACCS plants need very little land and can be installed virtually anywhere. This technology can become particularly important in the future if society is unable to curb emissions to sufficient levels soon and the atmospheric concentration of GHG needs to be artificially reduced. DACCS activities are completely dependent on potential revenues generated from CDR as – differently from BECCS and CCS in industrial processes – they are not part of any other economic value chain.

CO₂ Transportation

While transportation infrastructure is not a CCS application per se, it constitutes a crucial element in the CCS value chain. CO₂ generally needs to be transported under high pressure and at present, this can be done mostly via pipelines or, alternatively, in ships or trucks. The large scale deployment of CCS depends on the establishment and operation of transport networks, and a coordinated approach at international, national or regional levels is the most efficient way to achieve this. The nature of CO₂ transportation activities creates an incentive to cluster CCS facilities and to centralise the operationalisation of the network in one or few operators (e.g., similarly to electricity grid and water supply infrastructure).

2.4. Supporting the different RDD&D stages for CCS

Revenue needs of CCS vary along the different RDD&D stages – largely as a function of the cost reductions enabled as technologies develop. A generic RDD&D cycle can be divided into four phases: (i) piloting, research and development; (ii) demonstration; (iii) deployment; and (iv) commercialisation (IEA 2010).

Earlier RDD&D phases require significant upfront capital to initiate technology development activities, and ‘first-of-a-kind’ projects usually require dramatically larger amounts than subsequent ones. Current carbon market structures generally pay a fixed amount for each incremental tonne of CO₂ reduced or removed, which brings challenges

for CCS technologies where the cost of the initial removals is likely to be much higher than later removals.

Figure 5 offers an overview of different elements of the CCS ecosystem requiring revenue or regulatory incentives. The current landscape is mostly dominated by pilot activities (including the demonstration activities enabled through DemoUp Carma), but there is an opportunity for scale-up activities to be incentivised.

Investment decisions are generally driven by the prospective returns they are likely to bring and the risks involved. Hence, the availability of funding for RDD&D is largely dependent on incentives such as credible public policy signals that indicate carbon revenue streams are likely to be secured once CCS technologies mature.

The EU ETS, for example, incentivises emission reductions and removals by making the carbon-intensive alternative more expensive due to the cost of purchasing allowances. While this has to some extent incentivised investments into CCS development, these are still not enough to scale-up technologies sufficiently, and further revenues and incentives are required.

The near-term supply push that support for the RDD&D of an emerging technology can deliver, versus the long-term demand-pull that market instruments or regulations requiring technology adoption can induce, should also be considered when assessing and designing incentives for CCS value chains. Subsidies, for example, tend to be best used initially and then become increasingly ineffective and expensive once technology adoption accelerates. This has been observed with the support provided to scale-up renewable energy generation later becoming increasingly costly and difficult to justify. Meanwhile, mature carbon markets and regulations are often unable to – on their own – support early-stage innovations.

Figure 5: Investment- and operation-related costs that may require carbon revenues.

		PIONEERING PHASE			SCALING PHASE				
		2022	2025	2030	2035	2040	2045	2050	
NET-STRATEGY		Project DemoUpCARMA							
INTERMEDIATE STAGES		CO ₂ capture from biogas upgrading plants							
		Large-scale CO ₂ capture, e.g. waste incineration plants, cement plants,...							
TARGET VALUE (MtCO ₂ e _{stored} /y)					0,5	1,0	2,0	5,0	7,0
CAPTURE	CO ₂ capture facilities (incl. further steps for pipeline-ready CO ₂)	Capital incentives for facilities via direct grant: "Pilot- und Demonstrationsprogramm" (BFE)							
		Operational expenditures: upstream efficiency loss by CO ₂ capture process and energy demand of CCS infrastructure							
TRANSPORT	CO ₂ transport via truck, rail & ship	Capital incentives for low emission transport, e.g. biogas truck, H ₂ -powered ships							
		Operational expenditures: energy demand of transportation							
	First pipeline sections and clusters					Upfront investment for pipeline infrastructure			
						Operational expenditures: energy demand pipeline transport			
	Expansion of national pipeline infrastructure and international					Upfront investment for pipeline infrastructure			
						Operational expenditures: energy demand pipeline transport			
INTERMEDIATE STORAGE						Upfront investment in possible temporary CO2-storage domestically and abroad (including technical solutions, responsibilities, financing)			
DOMESTIC STORAGE	CO2 storage in building materials (e.g. concrete) and in domestic geological formations	R&D activity-oriented subsidies for industrial-scale demonstration plant (Neustark's CO ₂ -storage technology)							
		Mitigation-oriented subsidies for scale-up (Neustark's CO ₂ -storage technology)							
		National programme for exploration of suitable sites & pilot projects for CO2 storage in Swiss underground							
STORAGE ABROAD	Geological CO ₂ storage abroad	Domestic geological CO ₂ storage							
		R&D activity-oriented subsidies for pilot-scale demonstration of mineralization of CO2 dissolved in seawater (Carbfix)							
INVESTMENT IN NET ABROAD		Operational expenditures: commercial transport and geological storage services							
		R&D activity-oriented subsidies for research and innovation projects and participation in relevant research infrastructures							
		Bilateral state treaties to comply with international provisions such as the Paris Agreement and the London Protocol							
COLOR CODING		Governmental intervention		Revenue requirements					

Source: The authors

3. Overview of relevant Swiss policies for the accounting and financing of CCS

3.1. Swiss revised CO₂ Act

Switzerland's most important domestic legal instrument to mitigate national GHG emissions is the Federal Act on the Reduction of CO₂ Emissions (CO₂ Act), implemented by the 'Ordinance on the Reduction of CO₂ Emissions' (CO₂ Ordinance) (Library of Congress 2021).

Swiss law has three core policy instruments that could shape incentives for CCS value chains:

- The Swiss ETS (linked with the EU ETS)
- The obligation to compensate for the GHG emissions resulting from the use of motor fuels
- Sector agreements (for waste incineration and buildings)

3.1.1. Overview of the CO₂ Act

The CO₂ Act stipulates that Swiss GHG emissions must be reduced by 20% by 2020 compared to 1990 levels. This target was not quite met, with GHG emissions falling by 19% only (Federal Office for the Environment, 2022, Inventaire). GHGs covered by the Act are the following: CO₂, CH₄, N₂O, HFCs, PFCs, SF₆, and NF₃.

Since 2008, under the CO₂ Act, the Government of Switzerland has administered a carbon tax – officially referred to as a 'CO₂ levy' – on all fossil thermal fuels, such as heating oil and natural gas. The CO₂ levy aims to make fossil fuels more expensive, thereby creating an economic incentive to use them more sparingly and increase the consumption of low- and zero-carbon energy sources. As of 2022, the levy rate amounts to CHF 120 per tCO₂, which is the maximum rate the Federal Council can impose under the current act (Federal Office for the Environment n.d., CO₂ levy).

An ETS has also been operating since 2008. The ETS covers all GHGs covered by the CO₂ Act from the following sectors: domestic aviation, industry and power generation (International Carbon Action Partnership [ICAP], 2022). The Swiss ETS linked with the EU ETS in 2020, meaning that emission allowances allocated by operators of both systems are fully fungible. At the most recently concluded auction, held in June 2022, the auction clearing price was EUR79.10 per allowance⁴ (Federal Office for the Environment 2022, Welcome to the Swiss Emissions Trading Registry).

Following the Government of Switzerland's ratification of the Paris Agreement and submission of its updated NDC, in which the Swiss government pledged to both reduce its GHG emissions by at least 50% by 2030 compared to 1990 levels and achieve net zero GHG emissions by 2050 (Government of Switzerland 2021, Switzerland's information necessary), the Swiss Parliament adopted a revision to the CO₂ Act, which became subject to a facultative referendum. On 13 June 2021, Swiss voters rejected the revised CO₂ Act (Library of Congress 2021).

In the wake of the rejection of the referendum, the Swiss Parliament approved an extension of the CO₂ Act that will enable Switzerland to continue to reduce its GHG

⁴ One allowance equals one tCO₂.

emissions by 1.5% annually through 2024 via the implementation of primarily domestic GHG emission reduction measures (Government of Switzerland 2021, Switzerland's information necessary). On 17 December 2021, the Swiss Federal Council launched a consultation on a revision to the CO₂ Act for the period 2025–2030 (Federal Council 2021). The aim of this revision to the CO₂ Act is the achievement of the Government of Switzerland's goal of cutting Swiss GHG emissions by at least 50% by 2030 relative to 1990 levels. In light of the Swiss population's rejection of a previously proposed revision to the law, the Federal Council maintains that the proposed revision does not rely on policy instruments rejected by voters in the June 2021 referendum (Federal Council 2021). The Swiss Federal Council will submit to the Swiss Parliament a revision of the CO₂ Act in the latter part of 2022 for the post-2024 period. To avoid a regulatory vacuum until 2025, in spring 2022 the Swiss Federal Council approved a modification of the CO₂ Ordinance that keeps the undisputed instruments of the CO₂ Act in force (Federal Council, 2022).

3.1.2. Inclusion of CCS in the amendments

The revised CO₂ Ordinance maintains the compensation obligation imposed on importers of fossil transport fuels (Federal Council, 2022). Compensation must take place via the implementation of carbon projects located either in Switzerland or abroad. The revised CO₂ Ordinance newly permits carbon compensation projects involving the long-term storage of CO₂ in biological sinks (e.g., forests or soils) or geological sinks (e.g., underground storage or building materials). This creates an incentive for conducting CCUS and CCTS projects in Switzerland and abroad.

CO₂ geologically stored by compensation projects may derive not only from atmospheric and biogenic sources, but also fossil sources (in addition to processes associated with fossil fuels). CO₂ derived from the atmosphere or biogenic sources are considered to be GHG removals, whereas CO₂ derived from fossil sources are considered to be GHG emissions reductions (Federal Department of the Environment, Transport, Energy and Communications & Federal Office for the Environment, 2022). Carbon projects involving CO₂ storage in biological and geological sinks must ensure that emissions remain stored for at least 30 years.

Outside of Switzerland, compensation projects with geological storage are eligible to be issued credits for the Swiss compliance market. New projects abroad must demonstrate how they contribute to local sustainable development, as required under the CO₂ Act. However, carbon sequestration projects involving biological reservoirs abroad are excluded from the compensation mechanism and cannot generate credits. According to the Swiss Federal Council the risk of storage reversal cannot be sufficiently secured for these projects due to, for example, changes in land use or natural phenomena.

For compensation projects with biological sequestration involving forests (e.g., forest regeneration), both forest functions outlined in the Swiss Forestry Act and soil quality (e.g., no acidification) need to be preserved, in addition to the sink capacity.

To guarantee the long-term storage of CO₂ for biological sinks in Switzerland, the revised CO₂ Ordinance stipulates that the land under which the CO₂ is stored be subject to a restriction of public right to land ownership registered in the land register (Federal Department of the Environment, Transport, Energy and Communications & Federal Office for the Environment, 2022). CO₂ removals that are reversed by, for example, a forest fire, can no longer be used to compensate for transport fuel GHG emissions. If the

credits issued for these removals have already been surrendered to achieve compliance with the obligation to compensate for transport fuel emissions, an equivalent number of valid credits must be surrendered in their place.

The requirements for carbon projects involving the long-term storage of CO₂ in biological sinks and geological sinks are summarised in Table 1 below.

Table 1: Requirements for compensation projects involving carbon storage

Requirements	Projects involving biological sinks	Projects involving geological sinks
Activities	Storage of CO ₂ in biological sinks, e.g., forests or soils.	Storage of CO ₂ in geological sinks, e.g., underground storage or building materials.
Eligible locations	Switzerland.	Switzerland and abroad.
CO₂ origin	CO ₂ from biogenic and fossil sources.	CO ₂ from biogenic and fossil sources.
Sustainability	Biological projects need to demonstrate how forest functions and soil quality are preserved.	Geological projects abroad need to demonstrate how they contribute to local sustainable development.
Land ownership	The land under which the CO ₂ is stored must be subject to a restriction of a public right to land ownership registered in the land register.	No requirements.
Permanence	Emissions must remain stored for at least 30 years.	
Risk of reversal	Credits derived from CO ₂ removals that have been reversed can no longer be used to satisfy the compensation obligation. If the corresponding credits have already been surrendered, an equivalent number of valid credits must be surrendered in their place.	

(Source: the authors)

If the amount of CO₂ stored cannot be precisely quantified for a given project, credits can still be issued if the project is accompanied by scientific monitoring from independent experts. Scientific monitoring should help mitigate quantification uncertainties through independent measures, additional measurements, critical discussion of results and publication of the monitoring approach in a scientific journal.

3.2. Swiss GHG emissions and carbon removals accounting

3.2.1. General approach for GHG emissions accounting

In 2004, Switzerland started to submit its National Inventory Report (NIR) annually under the UNFCCC. The FOEN is responsible for compiling the emission data and bears overall responsibility for Switzerland's national GHG inventory and the national registry.

Switzerland's GHG emissions and carbon sequestration in forests and harvested wood products are accounted for in its NIR. This inventory measures progress towards the

national target according to the CO₂ Act and Switzerland's international commitment under the Kyoto Protocol and the Paris Agreement.

According to the revised reporting guidelines under the UNFCCC (UNFCCC 2014a) and the Kyoto Protocol (UNFCCC 2014b), emissions are calculated based on standard methods and procedures provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006), its 2019 Refinements (IPCC 2019), the 2013 KP Supplement (IPCC 2014), and the 2013 Wetlands supplement (IPCC 2014a).

Switzerland's GHG emissions inventory details all of Switzerland's GHGs emissions according to the requirements of the UNFCCC. GHG emissions are broken down into gases, sectors, and individual sources.

The GHG emissions from international aviation and navigation and the GHG emission balance from land use (soil, vegetation) are detailed separately and are not included in the estimation of total emissions.

The inventory accounts for CO₂ emissions mainly originating from the use of fossil energy sources, industrial processes and waste incineration, and emissions of the other GHGs, such as methane (CH₄), nitrous oxide (N₂O) and synthetic gases, from a wide range of sources.

3.2.2. Approach for carbon removals accounting

Certificates generated by carbon removals are accounted for in a similar way as GHG emission reductions in the NIR.

To account for the permanence of carbon sequestration, each project needs to deliver a monitoring and verification report to the FOEN in 2030. If no monitoring report is delivered, it is assumed that a reversal and release of CO₂ has occurred.

Eligible projects include BECCS that happen in ETS installations. The CO₂ removals will be accounted for outside the Swiss ETS to not distort the emission allowances market – an approach aligned with the envisioned EU accounting framework for negative emissions at ETS installations (Swiss Gov, Revision des CO₂-Gesetzes). These negative emissions can be accounted for in the framework of compensation projects within the Swiss scheme requiring the compensation of the GHG emissions resulting from the use of motor fuels.

Similar to the existing regulation in the ETS of the European Union, carbon capture and storage of fossil CO₂ emissions can be accounted for in the Swiss ETS. The regulation allows for any form of CO₂ transport (i.e. for trucks, trains, ships, pipelines). It mandates geological carbon storage in an underground facility in the European Economic Area (EEA) or storage in durable products such as building materials.

3.3. Swiss climate finance instruments supporting CCS

Swiss Emissions Trading Scheme linked to the EU ETS

Following almost a decade of negotiations, approval, and ratification procedures, the Swiss ETS linked with the EU ETS in 2020. While the linking of the Swiss and EU ETSs ensures mutual recognition and full fungibility of both systems' allowances, it does not legally and institutionally entail a complete merger into one single ETS; the two systems prevail, yet functionally all participating installations in both systems are able to trade allowances from both (BAFU, 2022). Several decisions regarding scope and institutions

first developed in the EU ETS were also adopted in the Swiss system, including an extension of the scope to include aircraft operators for flights between EU member states and Switzerland, as well as the inclusion of fossil thermal power plants, the installation of a stability reserve, an accelerated decrease of the cap, and the adoption of EU benchmarks (ICAP, 2022).

Carbon capture and storage is included in the EU ETS, and the revision of the Swiss CO₂ Ordinance includes CCS towards emissions reductions, as well as towards achieving negative emissions within ETS compliance.

The waste sector, however, is not included in the ETS. Any waste incineration-based activities (e.g., BECCS) therefore cannot easily be incentivised via the EU ETS, and are equally not presently incentivised in the Swiss ETS.

In relation to leakage emissions from CCUS and CCTS, the EU ETS covers carbon capture, transport, and geological storage activities; and the corresponding entities must surrender allowances for leakages and adhere to a detailed MRV plan. This regulation will also be incorporated into the Swiss ETS (Bundesamt für Umwelt, 2021). Furthermore, revenues from EU ETS auctions finance the Innovation Fund (further detailed in section 3), which is also used to support CCUS or CCTS.

Article 6 transactions

Switzerland will explicitly rely on purchasing emission reductions and removals certificates from abroad to reach its NDC. It has proactively initiated and concluded bilateral agreements with several countries, making it a frontrunner in operationalising bilateral cooperation under Article 6.2. Under these agreements, Switzerland will most likely act as a buyer, paying for emission reductions generated abroad. However, the option of acting as a seller remains in the respective official documents (available at [Bilateral climate agreements](#)).

Switzerland has also signed agreements specifically addressing CCS and CDR with Iceland and the Netherlands. The first specifically mentions a potential Article 6.2 collaboration between the two countries. The agreement between Switzerland and Iceland targets the storage of CO₂. As Iceland's basaltic rocks are well suited for permanent storage and the country is expected to overachieve its NDC, it is likely that Switzerland will become the buyer country in this cooperation. The latter agreement with the Netherlands installs a joint working group to cover: 1) knowledge sharing in technical, environmental, geological, and transport-and-storage-related aspects of CCS and CDR; 2) considerations around the bilateral agreement, e.g., on cross-border transport and storage of CO₂; 3) policy and funding opportunities; and 4) other CCS and CDR-related topics to be decided jointly. It is unclear if this collaboration will eventually result in an Article 6 collaboration.

There is still legal uncertainty for transboundary CCTS activities resulting in CDR (notably DACCS and BECCS). This uncertainty stems from the very definition of CDR:

- If a CDR mitigation outcome is understood to be achieved once the carbon is durably stored, then CO₂ transported from a DAC plant in Switzerland to a storage site in Iceland would result in a mitigation result that Iceland owns. Iceland and Switzerland could, in this scenario, create an agreement through which Iceland sells internationally transferred mitigation outcomes (ITMOs) to Switzerland and simultaneously sources climate neutral (biogenic and atmospheric) CO₂ from

Switzerland. This transaction would create a market incentive for Swiss BEC or DAC installations.

- Alternatively, if the CDR outcome is understood to be achieved once biogenic or atmospheric CO₂ is captured with the intent of durable storage, then Switzerland would already ‘own’ the result and count it towards its NDC. Switzerland (or a private actor undertaking the BECCS or DACCS activity) would only pay for transport and storage services (to demonstrate storage intent), and the country that stores the CO₂ would not claim any mitigation outcomes. In this case, Article 6 would not play a role in the transaction.

In any case, as double-counting must be avoided under, each tonne stored can only be counted toward one country’s NDC.

Climate Cent Foundation and the Foundation for Climate Protection and Carbon Offset (KliK)

Established by the Swiss business community to fund carbon projects outside of Switzerland, the Climate Cent Foundation has launched a tender for carbon projects in the areas of negative emission technologies and CCS, with project ideas to be submitted by 30 September 2022 (Climate Cent Foundation n.d., Ausschreibung für CCUS/NET-Project). The foundation’s remaining assets – totalling between CHF 50 million and CHF 70 million – will be used to finance carbon projects in the aforementioned areas in Switzerland and abroad (Climate Cent Foundation, 2022). Emissions reductions financed for this purpose will be transferred to the Swiss federal government by 30 June 2032 at the latest and will comply with all Article 6 rules (Climate Cent Foundation 2022). To be selected, projects that remove CO₂ from either the atmosphere or point sources must permanently (defined as for “at least 30 years”) store the removed CO₂ in materials or subsoil. The storage of CO₂ in biomass is excluded (Climate Cent Foundation n.d., Begleitschreiben zur Ausschreibung NET / CC(U)S). Eligible credit vintages are 2023–2030, with payment for emissions reductions to take place upon delivery of the emissions reductions (Climate Cent Foundation n.d., Begleitschreiben zur Ausschreibung NET / CC(U)S). At least 20,000 ITMOs are expected to be generated by selected projects through 2030, and projects must enter operation by 2025 at the latest.

Established by the Swiss Petroleum Association in 2012 within the framework of Switzerland’s CO₂ Act, the Foundation for Climate Protection and Carbon Offset (KliK) fulfils Swiss mineral oil companies’ legal obligation to offset part of the GHG emissions associated with the consumption of the fossil motor fuels they sell. To do so, KliK funds carbon projects in Switzerland and abroad.

Motor fuel importers add a fee for each litre of motor fuel purchased. The collected fees are transmitted to KliK and are used to cover the expenses associated with the financing of the carbon projects KliK selects to fulfil mineral oil companies’ offsetting obligations. As of 5 July 2022, KliK has financed the reduction of more than 12 million tCO₂e (Foundation for Climate Protection and Carbon Offset, n.d., Home).

Since 2021, KliK has also served as the agency designated by the Swiss government to acquire ITMOs for the purpose of achieving Switzerland’s NDC. So far, CCS activities do not feature among the projects currently supported under KliK Article 6-related work.

Waste sector agreement

The Swiss government and the VBSA signed a sector agreement in March 2022. It obligates operators of municipal waste incineration plants to construct at least one

capturing facility by 2030 with the capacity to capture a minimum of 100,000 tCO₂ per year. To guarantee the success of the agreement, intermediate milestones must be met early between now and 2030. By 2023, for example, in depth feasibility assessments must be conducted to identify an incineration plant as the candidate for installation of the capture facility. This sector agreement follows up from the emission reduction goals set in 2014, which expired in 2021.

As CCS is expected to play a crucial role in Switzerland's long-term strategy of Switzerland (Federal Council, 2022), the implementation of sector agreements that specifically address CCS is important to enable climate mitigation in hard-to-abate sectors like waste incineration.

Swiss Technology Fund

Contracted by FOEN and managed by Emerald Technology Ventures and South Pole, Switzerland's Technology Fund offers loan guarantees to Swiss companies developing products that contribute to GHG emission reductions, promote renewable energy sources, more efficiently utilise electrical energy and/or conserve natural resources. The Government of Switzerland guaranteed CHF 350 million through the facility (South Pole n.d.), with the Technology Fund's guarantees provided only to loans from banks or other lenders based in Switzerland (Swiss subsidiaries of international firms can receive guarantees) (Technology Fund n.d., Target Group). Additional conditions of the loan guarantees are the following:

- Guarantees can total up to CHF 3 million
- Guarantees can have a maximum term of 10 years
- Every project supported must contribute at least 40% of the amount using other funds
- Annual fees of 0.9% of the guaranteed amount are levied (Technology Fund, n.d., Climate protection as overall target)

Criteria considered for selection by the Swiss Technology Fund include the following:

- The selected technology or product must have a positive environmental impact in one of the following four areas: reduction of GHG emissions, promotion of renewable energy sources, more efficient use of electrical energy and conservation of natural resources
- The selected technology or product must offer a sizeable market opportunity and have generated at least CHF 100,000 in sales
- The application must be creditworthy
- The selected technology or product must not be feasible without the guarantee
- The applicant – not just the lender – must be domiciled in Switzerland (Technology Fund, n.d., Climate protection as overall target)

The Technology Fund is an instrument of the Swiss government's climate strategy and is rooted in the CO₂ Act (Technology Fund n.d., Organisation). Since its launch, dozens of companies have received loan guarantees from the Technology Fund in a variety of areas, including, among others, energy storage, air pollution control and smart buildings (Technology Fund, n.d., Portfolio). CCS is also a project type eligible to receive support from the Technology Fund, though few applications in the CCS domain have been submitted.

SFOE funding

The Swiss Federal Office for Energy (SFOE) provides funding for innovative energy research and development projects through several programmes. Since 2021, 'SWEET' (Swiss Energy research for the Energy Transition) has targeted the early stages of applications contributing to the Swiss Energy Strategy 2050 and the Swiss climate goals. The fund is structured around topical calls, with a call on net zero being scheduled for 2024 (SFOE, n.d). A complementary fund called 'SOUR' (SWEET Outside-the-box Rethinking) supports high-risk innovations which are in the very early stages of R&D but have a high potential.

SFOE's 'Pilot and Demonstration programme' also provides support for R&D stages, including piloting and demonstration of technologies. While clearly targeting energy-related technologies, the programme encourages integrated approaches, possibly opening up the opportunity for CCUS and CCTS activities.

4. International landscape of existing and emerging incentives applicable to CCS

This section offers a global mapping and assessment of existing and emerging policy instruments, regulations, and financial mechanisms driven by the public and private sectors that are, or can potentially be, applicable to CCS activities.

CCUS and CCTS value chains are eligible in all key international policy instruments, but most do not currently appear to offer sufficient incentives for such projects. Numerous efforts for revisions are geared toward achieving carbon dioxide removal (CDR), but the notion of a circular carbon economy and the need to decarbonise industries has revived the attention paid to conventional CCS.⁵ Most instruments create what is sometimes referred to as a ‘compliance’ market, as they are tied into a demand source such as the requirement of achieving an ambitious NDC (through Article 6.2 or 6.4 transactions) or limiting net emissions to an allocated cap under an emissions trading system. The latter is, for example, the case for efforts on widening the scope of the EU ETS, as well as the development of a new mechanism to certify CDRs (CRCM) to generate units that can potentially be sold for compliance under the ETS.

Table 2: Overview of selected public policy instruments

Public policy instruments	Relevance for CCS
Paris Agreement’s Article 6.2	Bilateral cooperation that results in a transfer of mitigation outcomes which count towards the buyers’ NDC. The volume and price of the transaction are up to negotiations between the two involved parties. The supplier, in return, receives carbon revenue. Switzerland is an early pioneer in engaging (as buyer) in a range of Art. 6.2 transactions to demonstrate the feasibility and best practice of such cooperation and the possibility of building institutional capacity in the host country (the seller of mitigation outcomes). Mitigation resulting from CCS activities can be traded under Art. 6.2. With methodological work on storage solutions and the related ‘hot topic’ of permanence progressing, the importance of CCS is expected to play an increasingly important role in Art. 6.2 cooperation.
Paris Agreement’s Article 6.4 mechanism	The mechanism established by Art. 6.4 represents an internationally standardised form of transactions of mitigation outcomes such that common methodologies for quantifying results (baseline and MRV methods) and determining the additionality of the effort are used. Transactions are recorded centrally, and new project types (along with corresponding methodologies) must be approved by a central UN body. The carbon revenue from participating in Art. 6.4 transactions accrues only upon demonstration of the mitigation result. The big advantage of Art. 6.4 transactions is its global recognition and the currently developing market, which will likely involve all major industrial nations as potential buyers.

⁵ A CCUS or CCTS value-chain that involves durable storage can either achieve a reduction in CO₂ emissions or a removal of CO₂ from the atmosphere. This depends on the source of carbon. Capturing and storing fossil carbon from point sources (fossil fuel incineration or cement and steel process emissions) results in a reduction in emissions. Capturing and storing carbon directly from the atmosphere or from biological sources results in CO₂ removal.

Public policy instruments	Relevance for CCS
Kyoto Protocol's CDM	After a lengthy process, CCS activities have been accepted under the CDM since 2011, yet the carbon price level has not been sufficient to incentivise any CCS projects to date. Nonetheless, the CDM and associated guidance and regulation offer the internationally most extensive regulatory backdrop for international transactions (Art. 6.2 and 6.4). As a market, however, the CDM does not offer a meaningful source of demand as the EU ETS no longer accepts CERs as emission allowance.
EU Emission Trading System (ETS)	The EU ETS offers significant promise for long-term carbon revenue for activities in the sectors it covers. As a cap-and-trade mechanism, revenue stems from companies which will need to purchase allowances from others, if they do not limit their emissions to the allocated cap. CCS from energy plants in the EU represent activities which count toward emissions reduction efforts (and can thus indirectly result in revenue to over-achieving actors). However, plants that purely operate based on biomass-based fuels are excluded from the ETS and, therefore, cannot currently generate revenue from capture (BECCS). Revisions addressing this issue are being discussed, which would foresee including such plants and allocating free allowances corresponding to removal results, which then could be sold to generate revenue. The market stability reserve could also be used to tighten the cap (toward zero), thus raising the ETS price level and rendering CCUS and CCTS activities increasingly attractive.
EU Carbon Removal Certification Mechanisms (CRCM)	The EU Commission has set out to develop a tool for certifying carbon dioxide removal results from various activities. This is to strengthen comparability and credibility as a basis for later including more sectors/activities into the ETS (see above) or to enable removals to be sold into the ETS. Both approaches would allow generating carbon revenues for those CCUS and CCTS activities, which result in overall carbon dioxide removal (into durable storage) based on transparent rules – once operational. It is unlikely that the CRCM would allow the generation of removal certificates outside the EU. However, the mechanisms' tools might be available for use in a parallel system in Switzerland (or in the case of ETS inclusion, Switzerland and the EU could decide to mirror the same approach).
EU Innovation Fund	The Innovation Fund is the EU's most important tool for supporting the commercial demonstration of innovative low-carbon technologies in the EU. For the period 2020-2030, the Innovation Fund will provide around EUR 38 billion in funding for low-carbon technologies in energy-intensive industries, CCU and CCS projects, energy storage, as well as innovative renewable energy generation. The Innovation Fund will support up to 60% of the additional capital and operational costs of large-scale projects (above EUR 7.5m) and up to 60% of the capital costs of small-scale projects (below EUR 7.5m). Up to 40% can be given before the whole project is operational. As such, it can be a very important source of revenue for enabling new types of CCUS and CCTS activities in EU member states, Norway and Iceland (European Commission). The first call for large-scale projects was massively oversubscribed; the submitted proposals requested total funding of EUR 21.7 billion from an available budget of EUR 1 billion (European Commission, 2021a). Out of the seven projects selected during the first call, 4 are CCS projects (European Commission, 2021b). Among these projects, funding was granted to the Kairos@C project in Belgium, which aims to create the first and largest cross-border CCS value chain to capture, liquefy, transport and permanently store CO₂. Another selected project is the K6 Program by Air Liquide, which aims to decarbonise cement production by combining an oxy-fuel furnace with CCS.

Public policy instruments	Relevance for CCS
EU Connecting Europe Facility	The Connecting Europe Facility is a key EU funding instrument promoting growth and competitiveness through targeted infrastructure investment at the European level. It seems likely that this facility will be one of several instruments through which the EU seeks to support the development of geological storage sites in anticipation of a more systematic policy approach. Northern Lights, a joint venture of Equinor, Shell, and Total received EUR 4 million under the Connecting Europe Facility, and is currently the operator of the transport and storage component of Norway government's Longship Project – a full-scale carbon capture and storage infrastructure project (Northern Lights, 2022).
EU Sustainable Finance Taxonomy	The EU Taxonomy Regulation was published in June 2020 and defines a common language on what constitutes a sustainable activity, with the objective of reorienting capital flows towards sustainable investments, managing climate-change related financial risks and fostering transparency and long-termism in economic activity. CCS has been included in the Taxonomy, because it is a key technology for decarbonisation in the EU and enables other economic sectors and activities (i.e. steel, cement, electricity production) to operate in compliance with given thresholds. The inclusion of CCS in the Taxonomy ensures that CCS is viewed as a sustainable and can contribute to the increase of investment flows.
EU Member States CDR Plans	While there has been movement on EU level, a recent study has shown that no member state has a dedicated CDR strategy. Moreover, with the exception of Germany and Portugal, member states do not distinguish clearly between removals and emission reductions. (Ecologic Institute). In its National Energy Climate Plan (NECP), Germany specifically addresses the development of CCU and CCS technologies. For instance, DAC applications will be funded as a carbon technology under the Seventh Energy Research Programme.
US 45Q tax credit	Section 45Q of the Internal Revenue Code represents a US federal tax credit that applies for carbon dioxide sequestration. The Inflation Reduction Act, signed into law in August 2022, has made the 45Q significantly more generous and accessible to a broader array of developers and investors (Clean Air Task Force, 2022). In the revised 45Q, the minimum volume that must be captured to be eligible for the tax credit was drastically reduced from 100,000 tonnes CO₂e per year to just 1,000 tonnes per year for DAC facilities and 12,500 tonnes per year for industrial facilities. Moreover, it significantly improved the economics of CCS deployment by increasing the value of captured and stored carbon by 70% for point source carbon capture and enhanced oil recovery and more than 250% for DAC facilities (Pitchbook, 2022). The incentive level for CCTS would be significantly increased to USD 180 per tonne for DACCS; USD 85 per tonne for conventional CCS from carbon capture on industrial and power generation facilities; and USD 60 for CCUS (such as enhanced oil recovery). These expansions and enhancements are expected to dramatically scale CCS and CCUS activities in the US by as much as a factor of 13 (Carbon Capture Coalition, 2022). It is expected that 45Q will have a similar strong effect as the tax credits that led to the rise in wind and solar power generation.
UK's Carbon Capture and Storage Infrastructure Fund (CIF)	In November 2020, the UK government issued a ten point plan for a "green industrial revolution," which included a commitment to deploy CCUS in a minimum of two clusters by the mid-2020s and another four clusters by 2030, with the goal of capturing 10 mtCO₂ per year by 2030. For this purpose, the government created the Carbon Capture Storage Infrastructure Fund (CIF) endowed with GBP 1 billion. The CIF will support capital expenditure on transport

Public policy instruments	Relevance for CCS
	and storage networks and industrial carbon capture projects. Funds will be allocated through a cluster sequencing process, which will prioritise projects most suited to deployment in the mid-2020s. GBP 40 million have been committed to support early-stage design work in order to maximise participation in the fund.
California's Low Carbon Fuel Standard (LCFS)	The LCFS is a sub-national baseline and credit instrument in California that explicitly allows DACCS credits to reduce the carbon intensity of California's transportation sector.
Australia's Emission Reduction Fund (ERF)	In 2021, the Australian government developed a new ERF method to credit emission reductions from new CCS projects and award them with tradeable Australian Carbon Credit Units (ACCUs).
Sweden's reverse auction approach to public procurement	The Swedish government announced the procurement of a certain amount of removals from dedicated private entities via long-term commitments. Any interested organisations that could provide the volume of removals are eligible to participate in the auction scheme. The private entity with the lowest costs associated with this removal service would then win the auction and secure the removal assignment. Initially scheduled to take place in 2022, the first auction has been postponed until 2023 in light of ensuring compliance with European state aid rules and further regulations and conditions for implementation (Swedish Energy Agency, 2022). Reverse auctions are an attractive instrument because they incentivise cost-efficiency. Price discovery is also efficient as the bidding companies have the best knowledge of the costs per tonne removed. However, there are concerns that, at least for BECCS, the number of bidders is very limited and the technology is still not sufficiently mature. Moreover, as the deployment of CCS depends on different actors – capturing carbon, transporting it, and storing it is likely done by different companies – auction schemes may risk a loss in coordination on transport efforts, which would increase the CO₂ transporting costs (Lundberg, 2022).
Public mitigation targets as communicated in Parties' NDCs and LTS-LEDs	Even though not a public policy instrument per se, national or regional climate targets with a 2030 or 2050 time horizon can act as catalysts for the introduction of new policy instruments that support their achievement. Furthermore, they are instrumental in spurring demand for removals in the emerging Article 6 context, however, the extent to which NDCs rely on CCS is limited in practice. Of the 187 countries that submitted their NDCs ahead of COP21 in 2015, only ten explicitly mention CCS, including Switzerland, China, Saudi Arabia, the United Arab Emirates, and South Africa (Potsdam Institute, 2017). As of 2022, 33 countries plus the European Union have set themselves net zero targets either in law or policy, and more than 100 countries have proposed or are considering such a target (Climate Action Tracker, 2022). Since net zero requires balancing residual emissions with natural or technological removals, it can be expected that more countries will develop policies that aim to bring CCUS and CCTS to scale.
Dutch approach to Contracts for difference for offshore storage	The Netherlands awarded a large-scale CCS project in September 2021 based on a contract-for-difference (CfD) approach originally used for subsidising renewable energy. It offers an operating subsidy equal to the difference between the cost of value chains, including permanent storage and the market price of the alternative products without CCS. Projects compete in auctions for such contracts, and the subsidy level is adjusted annually to market conditions and

Public policy instruments	Relevance for CCS
	volumes. Incentives offered depend on the mitigation effectiveness of each method. In the context of the upcoming revision of the EU ETS, the European Commission has expressed interest in a European approach for contracts for difference. However, the introduction of this instrument is also viewed critically, notably by the Association of European Energy Exchanges. In their view, introducing CfDs could lead to short- and long-term distortions in the market. The introduction of what is effectively a price guarantee for low-emission technologies reduces the need for market participants to hedge their risks through participating in forward markets, leading to less liquidity and, consequently, less efficient price formation. This could compromise operational and investment decisions that are driven by price signals. Thus, the Association stresses that a comprehensive assessment of the impact on the carbon market should be conducted before CfDs are introduced at the European level (Europex, 2021).

(Source: the authors)

Table 3: Overview of selected voluntary private sector instruments

Private sector activities	Relevance
Voluntary carbon market	Although a large majority of transactions on the voluntary carbon markets have focussed on forestry and other land use-based approaches, as well as renewables and energy efficiency projects, increasing attention is given to the scaling of CCS-reliant projects. The CCS+ initiative is a notable example of this development, which is expected to play a significant role in bridging voluntary and compliance markets through the development of tools that should aid project developers to comply with the rules of, e.g., the EU ETS and the Article 6.4 mechanism.
Frontier advance market commitment	Frontier is an advance market commitment set up by Stripe, Alphabet, Shopify, Meta, and McKinsey that aims to accelerate the development of CDR by guaranteeing future offtake (up to 2030) for them.
Competitions with innovation support prices	Philanthropists, foundations, and individual corporations announced plans to set up dedicated programmes and distribute prize money to novel and pioneering removal solutions. Examples of these initiatives include the Bezos Earth Fund, Elon Musk's USD 100 m X-Prize for Carbon Removal, and Virgin's Earth Challenge. They can be particularly effective in aiding early-stage start-up teams as they often include guidance from experienced venture capitalists and entrepreneur experts.

(Source: the authors)

5. Gaps, challenges, and opportunities

This section discusses gaps and challenges associated with financing CCS and promoting its scale-up and opportunities to address them.

5.1. Gaps

Several supply push initiatives have been identified in Switzerland and globally to support CCS activities. However, stronger mechanisms to drive up the demand for CCS globally in the long-term are still to be developed.

Table 4: Examples of supply push versus demand pull instruments

Supply push	Demand pull
Grants and other financial support for pilot and demonstration plants <i>Example:</i> EU Innovation Fund	Regulations (sector agreements, carbon removal obligations, emissions standards) directly or indirectly requiring the use of CCS
Small-scale public procurement schemes for the purchase of limited volumes at a set price. <i>Example:</i> CfDs	Access to cap-and-trade systems allowing for compliance through CCS activities or credits with a sufficiently high and stable price level
Limited-scale private purchase contracts (including over multiple years) for credits by a small range of buyers <i>Example:</i> Frontier	Access to voluntary or compliance baseline-and-credit carbon markets of sufficient size, price level and stability, allowing for crediting of CCS results

While supply push initiatives can lay the groundwork for the design and implementation of demand pull instruments, they do not provide a sufficient level of revenue certainty for the payback duration of CCS investments. Currently, CCS projects are largely costly due to the significant expenditures associated with developing transport infrastructures, capture installations, and storage sites. Furthermore, the profitability of these projects only occurs in the long-term. To become financially viable at a large scale, CCS projects need a sufficient level of certainty on their future revenues, which can only be secured through strong and stable regulatory frameworks, credible methodologies for certification under carbon standards, and carbon prices that are high enough to cover CCS costs.

5.2. Challenges

Ensuring long-term stability of instruments

Experience shows that public policies are far from guaranteed to remain in place over multiple decades – which is an important condition for offering the kind of certainty over the carbon revenues needed to pursue CCS at scale and cost-effectively. Some successful exceptions for mitigation policies are selected carbon taxes in Nordic countries that have endured for decades. Another successful example is the implementation of feed-in tariff schemes (Ofgem, 2022) that contributed to the massive uptake of renewable and low-carbon electricity globally over the past decades. Hence, long-term stability is an important challenge to be considered in the design of instruments and regulations to support CCS.

Overcoming the valley-of-death

For activities solely or largely relying on carbon revenues, overcoming the valley-of-death⁶ is a particularly severe challenge as any loss in the credibility of future carbon revenues (e.g., due to carbon market price fluctuations or eligibility uncertainty) can completely undermine their financial feasibility. At present, CCS pilot projects tend to (or will) immediately cease operation once they have reached the end of any pilot support grants due to the lack of revenues to support their continuity.

Consistent demand and associated revenues are vital for creating a viable business case for the large scale deployment of CCS technologies. Hence, policy instruments should be designed to support technologies overcome the valley-of-death and ensure they reach commercialisation stages.

CO₂ storage supply and demand mismatch

As European countries move decidedly toward net zero emissions targets, the demand for durable CO₂ storage is expected to grow significantly in the medium term. Many capture projects currently at pilot-scale are expected to be scaled one or more orders of magnitude, while transportation and storage infrastructure development does not seem to scale in parallel. Should much of this scaling in CO₂ capture with storage intent coincide across European countries, bottlenecks are likely to emerge if the scaling of the development of transportation and storage infrastructure is insufficient. It is possible that transportation and storage services might go through a few waves of oversubscription, expansion, excess capacity and again oversubscription until a supply-demand balance is met.

Persistent investment risks

Even if robust demand-pull instruments are in place (e.g., for compliance under a carbon market), the investment risks associated with CCS projects might remain above the thresholds acceptable by private investors. Dedicated measures to attenuate investment risks where public sector agents take initial financial losses may be required to address this, including potential measures that smooth out fluctuations in market prices or create a price floor.

Inefficiencies and windfall profits for storage providers

Given the small number of present and prospective storage providers there is a risk of market concentration which can bring associated inefficiencies and consequently lead to excess costs for CCTS projects. The imbalance of information on the actual costs involved between storage providers and project partners or policymakers designing public purchase agreements or subsidies might contribute to this challenge – especially where financial flows come directly from government-administered budgets. Regulatory interventions can help address these issues.

⁶ The valley-of-death denotes a period during the early phases of development of companies and technologies, during which low market adoption and corresponding revenue overlap with large investment requirements for scaling production resulting in a rapid loss of capital – effectively a race against time reliant on the benevolence of early financial backers.

5.3. Opportunities

Carbon projects compatibility and Article 6 readiness

Project developers should design and implement emission reduction projects ensuring they would be ready to access the emerging Article 6.4 market and suitable for bilateral Article 6.2 transactions. This means already pursuing high-quality VCM standards (i.e. those endorsed by the ICROA) when participating in voluntary markets and gradually incorporating any measures provided in guidance for Article 6 or ETS readiness. The CCS+ initiative is expected to publish additional toolsets for guidance on how to apply, expand and adapt methodologies to specific carbon pricing or climate finance instruments beyond the VCM, such as Article 6 transactions.

Once the contours of the EU Carbon Removal Certification Mechanism (CRCM) become clearer – expected by the end of 2022 – similar guidance for compliance with the CRCM should also be developed and adopted to allow project developers to maximise their potential markets.

Development of de-risking instruments and provision of ensured carbon revenues for CCS activities

One of the biggest challenges associated with the carbon market is the lack of price stability. This creates a particularly significant barrier for projects that require massive initial investments while having lengthy pay-back periods – such as CCS projects. De-risking instruments can potentially create an important lever to make such projects viable.

CfDs are one example of a price guarantee instrument through which the difference between a pre-defined carbon price and the actual allowance price is paid to the project developer. This instrument – which has been used in the Netherlands in the context of CCS project – could potentially complement the Swiss and EU ETS by compensating for their price fluctuations, and creating a price floor for credits from CCS projects. However, the introduction of such an instrument could possibly lead to short- and long-term distortions in the market and a comprehensive assessment of the impact of CfDs should be undertaken prior to its potential implementation.

Long-term offtake agreements – a well-tested instrument in use in the carbon markets – can also contribute to the financial viability of mitigation projects that require more substantial upfront investments – such as CCS projects – through the provision of guaranteed returns. Recently, several advance market commitments have been announced by private sector consortia to promote the scale up of CCS activities through the purchase of as much removals as suppliers can manage (up to a budgetary ceiling) or the purchase a contractually fixed amount of removals at the least cost (with the possibility of increasing the volume). Governments could potentially devise similar instruments for results-based demand to incentivise the scale up of CCS activities.

Finally, the design and implementation of a tax credit instrument for CCS activities, inspired on the successful experience of the 45Q scheme in the United States could significantly contribute to promoting CCS deployment in Switzerland and the EU. It is expected that 45Q will have a similar strong effect as the tax credits that led to the rise in wind and solar power generation over the past decades.

Expansion of initiatives within KliK

The Climate Cent Foundation is currently engaging in long-term emissions reductions purchase agreements at a fixed price to give a sufficient certainty of investment returns for specific project types. With available funds, KliK could be directed to escalate this approach with a focus on CCS projects.

Coordination for the development of transportation and storage infrastructures

The development of transportation and storage infrastructure and the efficient operation of these activities will require a coordinated centralised approach at international, national or regional levels. Governments have an important role to play in (i) contributing to the development of transportation and storage infrastructure, and (ii) regulating transportation and storage activities to ensure fair access and efficient operationalisation. Experience can be leveraged from the market and regulatory structures used for the development and operation of water and electricity supply infrastructures.

Federal mandates could be allocated to: coordinate and regulate the development national transportation and storage infrastructures; engage in international negotiations and engagements regarding the linking of EU and Swiss pipeline infrastructures; and regulate the operation of these infrastructures.

In the absence of such federal mandates, Swiss cantonal and municipal governments can proactively engage in nationwide coordination to prepare the ground for an integrated national approach. A working group comprising representatives from cantonal administrations is being created by FOEN to address the long-term legal framework issues and the split of responsibilities between the cantons, the Swiss federal state and the private sector in enabling CCS activities. (Federal Council, 2022).

Development of appropriate insurance products

Standard setters could seek cooperation with insurance providers to jointly develop insurance solutions that address the technical and physical risks associated with CCS technologies – the most important being unexpected leakage of CO₂. Insurance instruments, as well as buffer pools, have in the past already been used to address leakage risks, mainly in the context of forestry projects (Dutschke et al., 2005) and a similar approach could be used for CCS activities. Buffer pools could alternatively be adopted as an insurance mechanism and they could be run by standard setters or alternatively by regulators in the context of compliance instruments.

Modification of the fossil fuel importers' obligations

The existing obligations imposed in Switzerland to importers of fossil fuels could potentially be modified to include a specific carbon removal obligation (e.g., as a fraction of the total compensation obligation). As a result, key actors in GHG intensive value chains would become responsible for removing or paying for the removal of part of the CO₂ emitted from their activities. This obligation could potentially be met through the purchase of permanent removal certificates, or alternatively through payments into a carbon removals fund that would centralise the purchase of removal certificates.

Another possibility that could be explored is the introduction of a carbon storage obligation scheme targeted as GHG intensive sectors. It could impose minimum CCS

obligations on particular sectors and allow for the trade of removal certificates between actors exceeding and failing to meet their obligations.

Improvements to the EU and Swiss ETS

While the Swiss and EU ETSs cover power and heat generation from fossil-thermal power plants (and any associated capture, transport and storage), biomass-based power plants are not covered. Thus, at present, both ETS fail to incentivise BECCS activities. A modification of both ETS could allow for the incentivisation of BECCS if biomass-based power plants were included and received free allowances (corresponding to the biomass-based carbon volumes of their operation), which they could sell to other actors subject to the ETS (Rickels et al., 2020).

For the EU, this potential modification would interact with the Effort Sharing Regulation creating a risk of double counting of biomass emissions. Furthermore, assuming biomass to be climate neutral can be problematic in some cases (i.e., where biomass production and harvesting is associated with direct and indirect emissions) and a potential solution could be awarding biomass installations “additional” allowances only for the net-removal achieved (Rickels et al., 2020).

Switzerland could still expand the scope of its ETS to include the waste sector, even if the EU does not, building on the experience from the New Zealand ETS, for example. Such inclusion could enable the allocation of allowances according to the biomass content and corresponding carbon removals achieved in waste-incineration-CCS installations.

At present ETS does not recognise emission reductions or removals in products (e.g., Neustark concrete). While this type of storage would be inherently durable, covering these activities under the ETS is not advisable as the scheme is focused by design on emitting installations.

Improvements to the accounting of carbon removals in Switzerland after the revised CO₂ Act

To improve the accuracy in the accounting of removal permanence, the number of years carbon is effectively stored should be taken into account. Under current legislation, any project removing carbon for at least 30 years is considered permanent (Federal Department of the Environment, Transport, Energy and Communications & Federal Office for the Environment 2022). Consequently, projects storing carbon for 30 years are accounted for in a similar way as projects storing carbon for 100 years.

This inaccuracy could be addressed by two approaches currently used in the voluntary carbon markets (e.g., by Verra) to compensate for any future reversals, namely pooled buffer accounting and tonne-year accounting, presented below.⁷ Both approaches consider a time horizon for carbon removals of 100 years.

Pooled buffer approach: Most carbon credit accounting mechanisms quantify removal projects using 100-year global warming potentials (GWPs). Therefore, removals must remain stored for 100 years to achieve the calculated benefit. Risks of reversals are managed by withholding a portion of the removal credits generated in a pooled buffer account that can be used to compensate for any future reversals.

⁷ <https://verra.org/wp-content/uploads/2022/04/Tonne-year-additional-background-2022.04.01.pdf>

Tonne-year accounting: Tonne-year accounting quantifies the benefit of carbon removals on an annual basis, enabling sequestration projects to quantify the benefits of carbon storage in the short term. The sequestration activity is credited based on the number of years the carbon is held out of the atmosphere using an annual factor derived from the 100-year decay curve of CO₂ in the atmosphere.

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Stakeholder engagement

DemoUpCARMA

Work Package 5: addressing policy, regulatory and acceptance challenges to enable CCUS deployment

Task 1: emissions accounting, reporting tools and climate finance mechanisms of negative emissions for national and transnational CCUS solutions

Zurich, 20 October 2023

Details

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Table of contents

Executive summary	Error! Bookmark not defined.
Introduction	4
Stakeholder engagements during the stocktaking phase	5
Stakeholder engagements during the climate finance assessment phase	6
Stakeholder engagements during the methodology development phase	7
Stakeholder engagements during the blueprint development phase	8

Acronyms and abbreviations

CCS	carbon capture and storage
CCTS	carbon capture, transport and storage
CCUS	carbon capture, utilisation and storage
CO ₂	carbon dioxide
EC	European Commission
EU	European Union
FOEN	Swiss Federal Office for the Environment
UN	United Nations
US	United States
VCS	Verified Carbon Standard
WP	work package

Introduction

Task 1 of Work Package (WP) 5 of the DemoUpCARMA project involved stakeholders in numerous manners and for various purposes.

Interactions took place through:

- stakeholder survey targeting regulators, emitters and carbon capture, utilisation and storage (CCUS) solution providers;
- online and in-person bilateral and group discussions in various formal and informal settings with Swiss and European CCUS industry stakeholders and experts on specific questions of domestic or international law and market instrument developments;
- engagements with Swiss, European Union (EU), United States (US), Swedish, Icelandic, German, and United Nations (UN) regulators on specific policy questions regarding emerging instruments of relevance to the (future) monetisation of CCUS; and
- project-internal meetings and interactions for mutual learning, capacity development, and shaping project outputs most productively.

The respective focus of these engagements across different phases of the work on Task 1 is outlined more specifically in the following sections.

Stakeholder engagements during the stocktaking phase

Given the early stages of mainstreaming CCUS and carbon capture, transport and storage (CCTS), stakeholder engagement was a relevant step during the stocktaking phase to gather insights on where different actors see the most pressing need for advancement. The primary method used was an online survey questionnaire including both broad and detailed questions, aiming to gauge stakeholder opinions on CCUS and CCTS and the limiting factors toward a working business case.

The team developed questions tailored to the different types of stakeholders, grouped into three categories: regulators, emitters, and technology and service providers. The questionnaires were designed to cover several areas of interest: the foundational understanding of CCUS and CCTS, potential financial challenges, the current regulatory environment, technical viewpoints, and the hurdles related to public acceptance and communication.

The feedback from this engagement offered some clear patterns. Regulators were found to have the most comprehensive understanding of CCUS and CCTS, with emitters following closely. The technology and service providers showcased detailed knowledge in their respective fields of the CCTS/CCUS value chain. Financially, there was a preference among stakeholders for a market-based approach to funding CCUS and CCTS projects over a more rigid approach. However, the lack of clear regulations has introduced uncertainties, especially around risk assessments and carbon pricing, affecting investments in CCS infrastructure. On the technical side, while the capability to capture carbon dioxide (CO₂) is available, there are concerns about transportation and storage. The absence of a well-planned pipeline infrastructure for CO₂ transport was highlighted as a significant concern. Public acceptance of CCS technologies emerged as a critical point. The consensus was that public understanding of these technologies, especially in the context of climate change, directly influences their acceptance. This is particularly relevant in Switzerland, where citizen input plays a significant role in shaping regulatory decisions through referendums. Therefore, enhancing public knowledge of CCS solutions is deemed crucial.

Co-funding by a European project allowed repeated interaction with diverse CCUS technology-focused stakeholders from a dozen European countries. This allowed the team to identify stakeholders' views and understandings of the barriers and potential opportunities leveraging carbon markets, and help them overcome such barriers through robust monitoring, reporting and verification (MRV) systems.

These interactions enabled the team to refine the work plan for subsequent phases.

Stakeholder engagements during the climate finance assessment phase

During the second phase, the assessment of the climate finance landscape and opportunities for CCUS and CCTS, the team engaged in various contexts with stakeholders to identify their current levels of understanding of carbon market requirements and their expectations for future scalable revenue opportunities.

The team engaged – along with other private sector actors – on the question of what issues needed to be addressed in bilateral state agreements as a foundation of future transboundary CCUS value-chain projects at the invitation of the Swiss Federal Office for the Environment (FOEN).

The team engaged with stakeholders in the pertinent EU, US, and UN processes to gather the most up-to-date information on likely requirements for CCUS and CCS project developers under the respective instruments under development, especially regarding the EU Emissions Trading System (ETS), the tax break 45Q in the US, and the Swedish bioenergy with carbon capture and storage (BECCS) reverse-auction system under development.

The team also interacted informally with European CCS and CCUS industry actors and experts from a dozen European countries to track developments concerning MRV and accounting-related national CCS legislation and international regulatory environments, including the London Convention and Protocol (Norwegian legal experts), the Helsinki Convention regarding storage in the Baltic Sea Region (a Swedish legal expert), or the Convention on Biological Diversity (CBD). The latter, for example, comprised an exchange with a member of the UN CBD Secretariat to understand any prospective changes to provisions regarding “geo-engineering” that may hold implications for sub-seabed storage of CO₂ at large scale.

Stakeholder engagements during the methodology development phase

The team was also continually informed by stakeholder engagement taking place under the CCS+ Initiative's work – especially in the context of the work on D.5.2 (development of a comprehensive ensemble of baseline and MRV methodologies for CCUS project types). Central to this engagement was the continuous interaction with over 40 CCS and CCUS actors members of the CCS+ Initiative.

Another important cluster of interactions emerged with the interest of international regulators in this MRV toolkit and included repeated engagements with the European Commission (EC), the US Department of Energy and the UN's Article 6.4 supervisory body. As an example, the EC is closely following the development of the methodologies. The CCS+ Initiative has held two workshops with EU regulators and policymakers representing Directorate-General for Climate Action (DG CLIMA), the CCS Directive, and the carbon removal certification framework (CRCF), among others. Furthermore, it is due to present the methodologies at the EU Expert Group meeting on Industrial Removals on the 25–26 October 2023.

These interactions included the provision of input into their respective processes, providing lessons-learned from the Verified Carbon Standard (VCS) methodology development applicable to these emerging compliance carbon market systems. They also served to bring observations from evolving regulatory considerations into the VCS requirements, and to build their consideration into the D.5.3 work on methodologies and accompanying tools for maximum compatibility and future compliance.

During this phase, insights and findings from research conducted under DemoUpCARMA WP2, WP3 and WP4, including on lifecycle assessments and other pertinent techno-economic assessments, were considered for informing the MRV requirements as well as the requirements for testing of additionality. Additionally, the discussions and interactions between researchers and partners at DemoUpCARMA meetings have proven highly informative.

Stakeholder engagements during the blueprint development phase

Furthermore, the development of accompanying tools has benefited from an improved understanding of stakeholders' requirements and information needs regarding the procedures involved in pursuing a carbon market project. Here, it was also highly relevant to engage in mutual learning – also with actors at the European level – to understand the intricacies and various possible models of developing institutional arrangements that are fit for the purpose of pursuing carbon crediting with the heterogeneous actors involved in a CCUS value chain.

Already the selection of the most pertinent types of blueprints proved contentious, as ideally there would be a guiding document for every single type of value-chain (any combination of a capture, transport and storage or utilisation technology) as well as for any geographic combination (domestic, transboundary, foreign) and for any market instrument type. Such diversity of combinations, however, would yield an unmanageable number of guiding documents with a very high degree of redundancy. Finally, a selection was adopted, which likely represents the starting point for a growing number of tailored guidance, including down to the level of individual projects, that are prepared and submitted to a voluntary carbon market standard or another market instrument domestically or internationally.

The development of these guidance documents drew heavily on a continuing interaction with stakeholders described in the preceding phase with regard to the development of methodologies and, additionally, involved several discussions with FOEN and with project partners on the most pertinent scope, content and form.

Strategy paper: Enabling CCUS value chains for Swiss climate neutrality

DemoUpCARMA

Work Package 5: addressing policy, regulatory and acceptance challenges to enable CCUS deployment

Task 1: emissions accounting, reporting tools and climate finance mechanisms of negative emissions for national and transnational CCUS solutions

Zurich, 15 December 2023

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Table of contents

Executive summary	7
Introduction	15
Background	16
Aim of the report	16
Main barriers and challenges to consider	17
Analytical framework – development of policy instruments and private initiatives	19
Policy instruments and private sector initiatives – categories and introduction	19
(Dis-)incentivisation instruments	21
Regulatory instruments	21
Market generation instruments	21
Direct funding instruments	22
Sectors	22
Policy instruments and private sector measures	23
Incentivisation	24
Carbon-price-floor-inducing instruments: CfDs, industry sector pooling for carbon pricing top-up and carbon-price-adjusted tax breaks	24
Public-private coordination and cooperation on transport and storage infrastructures	27
Market generation	29
Advance purchase agreements in compliance or voluntary carbon markets	29
Domestic offsetting for compliance with the compensation obligation	31
Inclusion in ETS compliance	33
Inclusion in international compliance carbon markets	36
Regulations	39
Sector agreements	39
Direct funding	41
Direct funding	41
Public procurement	43
Policy instrument review summary	45
Sectors and their strategies	51
Solid waste incineration	51

Strategy paper

Profile	51
Challenges	52
Strategy	53
Summary	55
Liquid waste	56
Profile	56
Challenges	56
Strategy	57
Summary	59
Cement plant CO₂ - capture, sludge co-firing and mineralisation	60
Profile	60
Challenges	60
Strategy	61
Summary	63
Strategies regarding underground storage and transport	64
Conclusion	66
References	69

List of tables

Table 1: Summary of other regulatory instruments that could be employed	8
Table 2: Summary of the considered policy approaches and their suitability in the short and long term	10
Table 3: Overview of the solid waste incineration sector profile	12
Table 4: Sector-specific considerations for application of policy instruments	14
Table 5: Selected policy instruments	25
Table 6: Carbon price floor inducing instruments	28
Table 7: Public-private coordination and cooperation on transport and storage infrastructures	30
Table 8: Advance purchase agreements in compliance or voluntary carbon markets	33
Table 9: Domestic offsetting for compliance with the compensation obligation	35
Table 10: Inclusion in ETS compliance	39
Table 11: Inclusion in international compliance carbon markets	42
Table 12: Sector agreements	45
Table 13: Direct funding	47
Table 14: Public procurement	50
Table 15: Summary of the considered policy approaches and their suitability in the short and long term	52
Table 16: Overview of the solid waste incineration sector profile	62
Table 17: Summary of the liquid waste sector profile	67
Table 18: Summary of the cement sector profile	71
Table 19: Sector-specific considerations for application of policy instruments	75

List of figures

Figure 1: The four levers policy interventions and private initiatives can pull: incentivisation, market generation (voluntary and compliance), regulation and direct funding	20

Acronyms and abbreviations

BECCS	Bioenergy with carbon capture and storage
CCS	Carbon capture and storage
CCU	Carbon capture and utilisation
CCUS	Carbon capture utilisation and storage
CDR	Carbon dioxide removal
CfD	Contract-for-difference
DAC	Direct air capture
DACCS	Direct air carbon capture and storage

Strategy paper

ETS	Emission Trading System
EU ETS	European Union Emission Trading System
GHG	Greenhouse gas emissions
KIG	Federal Act on climate protection targets, innovation and strengthening energy security
NDC	Nationally determined contribution
NO _x	Nitrogen oxides
RDD&D	Research, design, development and demonstration
SO ₂	Sulphur dioxide
tCO ₂	Metric tonne of carbon dioxide
UVEK	Federal Department of Environment, Transport, Energy and Communications
VBSA	Swiss Waste Treatment Installations
VCM	Voluntary carbon market
VSA	Association of Swiss Wastewater and Water Protection Professionals
FOEN	Swiss Federal Office for Energy

Executive summary

Background and objective. Carbon capture, utilisation and storage (CCUS) activities are critical for addressing climate change. However, due to high implementation costs, limited revenues outside of carbon-related incentives and the lack of supporting policies, it is difficult to establish a business case for their implementation. To enable their upscaling and help them reach maturity, policy support and cooperation between public and private actors will be required.

This paper outlines a range of policy instruments and subsequent strategies that have the potential to strengthen the business case of CCUS activities. The strategies are differentiated based on their relationship with existing policy instruments and the different pathways of potential incentives. The report examines specific challenges in the three sectors that the DemoUpCarma project spans: solid waste, liquid waste and cement.

Policy instruments and private initiatives analysis. The policy instruments and private sector measures analysed in this report represent those policy options which have the potential to support the Swiss ambition in further developing and upscaling CCUS solutions. Building on the analysis undertaken in the briefing note (South Pole, 2022) preceding this report, four groups of policy instruments are discussed.

- **(Dis)incentivisation instruments**, which enhance the financial attractiveness of CCUS activities. Such measures are not necessarily tied to a specific project being implemented and some are not conditional to the actual delivery of carbon results. Possible approaches include:
 - Carbon-price-floor inducing instruments: Contract-for-difference (CfDs), industry sector pooling for carbon pricing top-up, and carbon-price adjusted tax breaks
 - Public-private coordination and cooperation on transport and storage infrastructures
- **Market generation instruments**, which pursue the development and advancement of carbon-results-based incentives via either a compliance demand (in ETS or Paris Agreement carbon markets) or by leveraging voluntary demand by private actors seeking to compensate emissions or make contribution claims towards accelerating decarbonisation. Possible approaches include:
 - advance purchase agreements in compliance or voluntary carbon markets;
 - domestic offsetting for compliance with the compensation obligation;
 - inclusion in an Emission Trading Scheme (ETS); and
 - inclusion in international compliance carbon markets.
- **Regulation instruments**, which can be used to compel the use of CCUS by particular actors (polluters, financial actors) or to complement financial incentivisation instruments. Possible approaches include (see also table X):

- sector agreements
- carbon-take-back obligation (obliging specific polluters to purchase or effect removals)
- technology standards and technology-specific obligations
- emissions standards (e.g. upper limit of CO₂-emissions per t of waste treatment that might require CCS or CCUS)
- **Direct funding instruments**, which involve the payment upon delivery of a specified volume of carbon emission reductions or removals. In contrast to incentivisation and carbon market generation, direct funding is tied directly to results of a specified mitigation volume or the meeting of a pre-specified development milestone. Possible approaches include:
 - direct funding; and
 - public procurement.

Regulatory instruments often allow the most direct application of a polluter-pays approach to internalization of costs, whereas (dis-)incentivization tends to be less stringent. Compliance market instruments also fit the polluter-pays approach, while also ensuring overall efficiency whereas voluntary carbon markets allow for the early testing, though not necessarily in line with the polluter-pays principle and not to be relied upon at scale.

Table 1: Summary of other regulatory instruments that could be employed

The Carbon Takeback Obligation is a policy instrument that obligates fossil fuel producers to 'take back' a percentage of carbon from the extraction process and ensure that it is permanently removed from the atmosphere. Currently policies focus on emissions that are produced by end-users while the production of fossil fuels occurs without restriction. This approach is synonymous with the polluter pays principle, whereby the producer, who directly or indirectly pollutes the environment, bears the costs of remedy or prevents it entirely.

Technology-standards and technology-specific obligations are a specific type of regulatory standard used for environmental regulation. They serve to govern a firm's activity to achieve certain environmental outcomes, and does so by mandating the use of specific technologies, for example CO₂ capture and storage methods at a power plant to reduce emissions. This is an advantageous policy instrument since it can be tailored according to the industry or company which therefore has the potential to reap significantly better environmental outcomes. As the regulator defines what technology should be used, there is further potential for such standards to be applied universally to other firms.

Emissions standards work similarly to technology-standards in that they govern pollution that is emitted into the atmosphere. They work by establishing limits for unabated CO₂ emissions and limits for allowed intensity of CO₂ emissions from fossil fuel generation.

Policy instruments often span several of the aforementioned categories, for example, the inclusion of a sector in an ETS contains both a regulatory aspect but also generates a market. Strengths and weaknesses of each approach vary depending on the technological maturity of the specific CCUS options. Further, the suitability may also differ between short-term and long-term perspectives. For this reason, a policy roadmap may need to draw on instruments in a staged manner. The key considerations in relation to the appropriate timing of introduction and phasing out of various support policy approaches follow.

- **Short and long term:** some policy instruments will be important both in the short and long term, such as: de-risking instruments; coordination and development of transport and storage infrastructure; and those instruments which can help create a stable and long-term demand for CCUS emission reductions or removals from the private sector (i.e. voluntary carbon markets; advance purchase agreements).
- **Short term:** policies relying on public funding would represent the most direct and straightforward instruments in the short term and can help CCUS technologies mature, however, their long-term use should be phased out with the expectation that the private sources of finance, such as voluntary and compliance carbon markets, will replace their funding.
- **Long term:** developing readiness for participation in compliance markets, which have high potential in the medium to long term requires early preparation. That said, international cooperation in relation to CCUS projects is already gaining attention in the EU and has a growing potential in the near to medium term if Switzerland mirrors some of these developments that hold long term promises.

The summary of the policy-level assessment undertaken in this analysis is shown in Table 1 (overleaf).

Table 2: Summary of the considered policy approaches and their suitability in the short and long term; **green** = suitable; **orange** = moderate; **red** = unsuitable

Policy instrument	Funder	Possible timeline	Overall potential	
			Short term	Long term
Incentivisation				
Carbon-price-floor inducing instruments	Public	Medium term		
Public-private coordination and cooperation on transport and storage infrastructures	Public/ private	Medium to long term		
Market generation				
Advance purchase agreements in compliance or voluntary carbon markets	Private	Short-, medium and long-term		
Domestic offsetting for compliance with the compensation obligation	Private	Short term		
Inclusion in ETS compliance	Private	Long term		
Inclusion in international compliance carbon markets	Public/ private	Medium to long term		
Regulation				

Sector agreements	Private	Medium term		
Direct funding				
Direct funding	Public	Short to medium term		
Public procurement	Public	Medium term		

Source: the authors (2023)

Analysis of selected sectors. Understanding sectoral specificities will play an important role in designing effective and efficient policy strategies. The three sectors analysed in this report are those hosting the demonstration projects under DemoUpCarma which have been selected for their opportunities for near-term demonstration of CCUS value chains. In addition to informing the design of specific policy approaches in the targeted sectors, their analysis might help understand the challenges and opportunities facing CCUS value chains in other sectors as well.

The sectors subject to the undertaken analysis are:

- **solid waste sector** – the capture of CO₂ at solid waste incineration plants
- **liquid waste sector** sewage sludge treatment and CO₂ capture
- **cement sector** – CO₂-capture, biomass co-firing and, CO₂-mineralisation (storage)

For each sector, the current situation, sector-specific challenges and possible policy strategies were analysed. Various strategies were proposed for each sector depending on whether the sector is already impacted by existing instruments, such as coverage under the existing ETS; the sector agreement or the compensation obligation; or whether it is eligible for domestic compensation. The strategies contained elements that required action by industry actors (or their associations) as well as by federal and in some cases cantonal legislators, and in many cases both. The summary of identified sectoral challenges and proposed policy strategies is presented in Table 3 (below).

Table 3: Overview of the solid waste incineration sector profile

Solid waste sector (approx. 4.2 MtCO₂ annual emissions)	
Challenges	• Additional purification methods for capturing CO₂ (cost implications) • Technical planning difficulties and socio-political criticism • Set volume for 2030 limiting incentive to go beyond • Clear post-2030 strategy missing: Risk of short-termism
Strategy	Given the existence of the sectoral agreement requiring the installation of one CCUS value chain, long-term incentives and mechanisms rewarding overachievement of the set targets would be crucial. Ensure systematic incentivization of CCUS, including the waste sector in the ETS (phasing out the regulatory approach) would seem beneficial in the long term. For ETS inclusion to offer a sufficient financial incentive to effect CCUS, the sector may, however, require some further support (shared public infrastructure) given the varying size of installations (risk capital to support access to transport infrastructures). The waste sector has the potential to overall achieve net-negative emissions; the cap should reflect this over time.
Liquid waste sector (approx. 0.3 MtCO₂ annual emissions)	
Challenges	• Clear targets for the short, medium to long term are needed, including interim targets until 2030 and post-2030. • Missing sector agreement • Insufficient current price levels to finance and bring down costs
Strategy	Introduction of a sectoral agreement similar to the one of the solid waste incineration sector could be an effective first step in promoting the introduction of CCUS technologies in this sector, yet it would require incorporation of certain

sector-specific amendments. Due to the higher cost of CCUS in the liquid waste sector, direct funding, public procurement and other instruments relying on public financial support would be needed in order to help relevant technologies mature. The importance of voluntary (early phase) and compliance (longer-term) markets for this sector is also high. To effectively engage with them, the cost of accessing CO₂ transportation and storage infrastructures will need to be reduced or publicly supported (public risk capital and additional support for the private sector and municipalities for shared infrastructure as per the KIG). Given the sector's highly dispersed range of small emission sources, the efficient implementation of a full CCS approach may prove challenging, and local carbon utilisation options could be promising. The liquid waste sector has the potential to overall achieve net-negative emissions; should it be included in the ETS then the cap should trend toward a negative figure over time.

Cement sector (approx. 2.9 MtCO₂ annual emissions)

Challenges	• Covered by ETS – so no binding sector agreement possible • Clear medium- and long-term strategy missing • More competition between sector's stakeholders • ETS revision needed
-

Strategy	This sector deserves special attention for the implementation of CCUS technologies due to its potential of implementation of the CCU as well as a higher level of competition which it faces in comparison to the solid and liquid waste treatment facilities. Therefore, in addition to the sector agreement and carbon market-related suggestions, specific policies increasing demand for low-carbon cement could be considered. They would include public procurement for low-carbon cement and allow for the inclusion of carbon storage in long-lived products, in line with the current proposal for the EU ETS reform.

Source: the authors (2023)

Design of the wider strategy. All of these considerations could feed into designing the wider policy strategy which would be able to support the development and upscaling of CCUS projects. This is due to the fact that the considered policy approaches in many cases will not work in isolation as challenges to piloting and later upscaling can be rather unique for each stage and technology. Moreover, they should be aligned with the country-wide technology priorities so it would be beneficial to develop a technology prioritisation and targeted emission reduction split on the national level to inform relevant policy decisions.

Strategies thus may be tailored to target the needs of each sector. Table 4 (below) shows the potential fit of instruments for each sector.

Table 4: Sector-specific considerations for application of policy instruments

Incentivisation	Solid waste	Liquid waste	Cement
De-risking instruments	Relevant for all sectors		
Coordination for the development of transportation and storage infrastructures	Relevant for all sectors		
Market generation			
Voluntary carbon markets: advance purchase agreements	Relevant for all sectors		
Domestic offsetting	Relevant for all sectors		
Readiness for ETS compliance	Inclusion in ETS could be suitable for the long term; widening the ETS scope to include biogenic carbon would strengthen the	Inclusion of storage in long-lived products could be considered	

	impact.		
Readiness for voluntary and compliance carbon markets	Build capacity to develop carbon projects ready for the voluntary carbon market or for future crediting (A.6 or CRCF); all sectors near and long term		
Regulation			
Sector agreements	Requires extended timeline and a mechanism to reward additional ambition	Requires a sectoral agreement, considering lessons learnt from the solid waste sector	Implementation would be desirable, but with the consideration that no market disadvantage should arise.
Direct funding			
Public procurement	Public procurement on the sectoral level is less relevant.	Public procurement is relevant given the higher costs of technologies in this sector	Public procurement can include not only carbon credits but also low-carbon cement.
Direct funding	Direct funding on the sectoral level is less relevant.	Direct funding is relevant given the higher costs of technologies.	Direct funding is relevant given the higher competition.

Source: the authors (2023)

Strategy paper

Additionally, direct government involvement in the development of transport and storage infrastructures appears to be necessary for CCUS to move forward.

Introduction

Addressing climate change is becoming increasingly urgent, and with climate neutrality targets it has become clearer that CCUS activities are critical (Global CCS Institute, 2022). However, the business case for CCUS has been difficult due to various obstacles and challenges, including: the high cost of implementation; limited revenues outside of carbon-related incentives; and the lack of supporting policies. This paper outlines a range of policy instruments and subsequent strategies that have the potential to strengthen the business case of CCUS activities including those that take place partly in Switzerland and abroad. The strategies are differentiated based on their existing coverage of policy instruments, along with the potential to extend, modify or build on them. The emphasis of the undertaken analysis is on providing incentives rather than creating obstacles through regulatory hurdles or permitting processes.

While the Swiss Climate and Innovation law (KIG) and the revision of the CO₂ law offer a promising basis, Switzerland's climate action still requires a more detailed regulatory and market operationalization to reliably bring about the steep downward net-emissions trend needed to meet the 2050 climate neutrality goal and net-negative emissions thereafter. The Swiss Federal Office of Energy projects achieving 11.7 million tCO₂ of emission reductions and removals through CCS and negative emission technologies by 2050, whereby the cement and chemical plants together with the waste incineration sector are expected to collectively reduce 6.5 million tCO₂ per year by 2050 through CCS (Bundesamt für Energie, 2020). The KIG offers key framing decisions on overall intermediate targets for 2030, and 2040 and mandates the federal council to specify these also at a sector level. It, furthermore, empowers the federal government to disperse necessary financial support to the private sector to trigger innovative technology applications via existing instruments, and it offers the possibility of providing risk capital to get investments into necessary shared infrastructures going (including likely CO₂-management transport infrastructures that may connect carbon-capturing sites with locations of utilization and storage including abroad. The law also mandates the federal and cantonal governments to ensure the provision of sufficient storage capacities. Furthermore, the sector agreement reached between the Swiss Government and the Swiss Association of Waste-to-Energy Plant Operators (Verband der Betreiber Schweizerischer Abfallverwertungsalagen [VBSA]) offers a valuable path to a first-of-its-kind installation from which others can learn. Yet, to scale and widen these measures systematically across all relevant sectors will require a step change in policy and private-sector initiatives. This is particularly relevant now given that the new climate legislation will be enforced from 2025 onwards, and will address the financing of innovative technologies and solutions, including CCUS, thereby facilitating a discussion on new regulations and instruments for the near future.

While this strategy paper does not offer policy recommendations, it outlines several possible courses of action to help finance and promote CCUS activities. Action could or may be taken both by government entities, including federal and cantonal authorities, as well as private sector actors to pursue CCUS in alignment with expectations and needs. Chapter 2 outlines the main barriers and challenges hindering the implementation of CCUS. Chapter 3 presents an introduction of key concepts – strategies, sectors, policy instruments and private sector initiatives and how these could support the development of CCUS. Chapter 4 provides an overview of policy instruments and initiatives, some of which are already in use elsewhere and could potentially support CCUS activities in Switzerland.

Strategy paper

Chapter 5 specifies the potential application of strategies for three-point source sectors: solid waste incineration; liquid waste; and the cement industry. By focusing on these areas, this paper offers insights into the specific challenges and opportunities of each sector and provides a basis for designing effective policies and initiatives to support the attainment of above-mentioned CO₂ reduction and removal goals in Switzerland.

Background

A survey conducted among CCUS stakeholders in early 2022 showed that there are various – and sometimes conflicting – expectations on how to incentivise carbon capture, transport, utilisation and storage. Essentially the divide was between placing key responsibility for creating incentives either with the (federal) government – or with private actors and their sector representatives or associations.

This is a complex problem that no country has fully addressed so far, even those that meaningfully strive for climate neutrality (Honegger, 2023). However, there are steps and strategies that offer partial solutions to identified challenges. To organise these expectations and strategies, this section provides background information on the theory and main concepts involved, as well as the main barriers and challenges that incentivisation strategies could address, which builds on the analysis undertaken earlier in the DemoUpCarma project (South Pole, 2022). It will also identify opportunities for action specifically in Switzerland.

Aim of the report

The main tenet of this report is that the successful piloting and scaling of CCUS (see Box 1) value chains requires deliberate interventions by public and private actors in order to overcome various barriers and challenges, especially in the absence of non-carbon-related revenues from sales of products or services. This report thus asks what might make such interventions successful in general and specifically in the cases of CCUS value chains covered by the DemoUpCarma project within the particular sectors concerned.

Box : CCUS terminology

CCUS stands for carbon capture, utilisation and storage. It refers to the process of capturing carbon dioxide emissions from industrial processes and power generation, using the captured carbon dioxide such that climate-relevant long-term storage is assured – variously for construction material production, enhanced oil and gas recovery or producing durable chemicals. We use the term CCUS only for use cases that do result in climate-relevant long-term storage and do not consider use cases that automatically result in a re-release of the CO₂.

This aligns with regulatory steps in the EU towards adopting a modification of its Emissions Trading System (see section 4.2.3) that allows the inclusion of CCUS if carbon is ‘permanently chemically bound in a product, and thus not released into the atmosphere under normal use’ (Erbach, Foukalová, 2023).

This report describes policy instruments as the means that enable the development of CCUS value chains through public policy. Public policies can also be complemented by private initiatives – sometimes these also strongly intersect. To be effective, policy instruments and private initiatives will need to fulfil the needs of those actors seeking to implement CCUS projects and activities. Policy instruments will need to address both short- and long-term barriers, gaps and challenges, differentiating between small- and large-scale projects. This report will describe four broad types of

policy instruments (see Section 4), each of which intersects with the short- and long-term needs for support of various technologies and sectors.

This report outlines the varying support needs and challenges across sectors, notably those that are involved in the DemoUpCarma case studies. In addition to those sectors (solid and liquid waste treatment and cement), the report also examines issues pertaining to CO₂ transportation and underground storage, which is not a distinct sector per se, but nonetheless represents a relevant category of (mostly) private sector actors for CCUS.

This report describes strategies as the tailored ensemble of instruments that are jointly capable of mobilising specific CCUS value chains within specific sectoral contexts.

Main barriers and challenges to consider

As identified in the briefing note, several barriers and challenges associated with financing and promoting the scale-up of CCUS exist to date. An overview of CCUS-related supply-side and demand-side gaps can be found in the briefing note as well. The key political and financial barriers and challenges for the CCUS landscape are as follows.

First, a lack of long-term reliable revenue sources. Most policy incentives to date focus on supporting the capital expenditures of building parts of the CCUS ecosystem, yet this alone does not provide for the necessary long-term revenue. Large-scale investments required for many parts of CCUS value chains also require a clear visibility of future revenues to achieve bankability. Therefore, the long-term, carbon-revenue outlook needs to be sufficiently robust. Dedicated policy and financing instruments need to demonstrate being able to provide a minimum revenue per tCO₂. Although several policy instruments to support CCUS activities have been discussed and also partially implemented to date, their long-term durability and impact in mobilising reliable revenues is key and needs to be monitored and, if necessary, adjusted. Certainty for investors, stakeholders and decision-makers requires legally binding long-term commitments and corresponding legal and institutional arrangements. At the same time, the rapid pace of innovation and the hopeful scaling in CCUS requires that policy instruments are continuously reassessed and adapted where needed (e.g. preventing that subsidies balloon and create windfall profits once CCUS value chains mature). Being empowered to access increasingly larger markets is particularly relevant for activity types that face a valley-of-death¹ when upscaled beyond piloting.

Early-stage and pilot activities require measures to attenuate the risk of insufficient carbon revenues as the barriers and initial costs are particularly large for first-of-their-kind activities. Measures to provide for such de-risking could include, for example, a public entity taking a first-loss position, but

¹ The valley-of-death denotes a period during the early phases of development of companies and technologies, during which low market adoption and corresponding revenue overlap with large investment requirements for scaling production resulting in a rapid loss of capital – effectively a race against time reliant on the benevolence of early financial backers.

various other risk-mitigation options have to be explored within the existing legal and institutional contexts.

Second, there is a risk of a mismatch between the CO₂ capacities of transport and storage providers and the demand for these services over time. Many of these elements have very long lead times as they require new infrastructures coming online. Demand for CO₂ transport and storage is likely to come in waves as it depends in large part on the subsidies, regulations and carbon market dynamics that may trigger rapid pressure for CO₂ capture on entire sectors of European countries. Scaling of transportation and storage infrastructures will have to rely on clear and plannable commitments to procuring transport and storage services of specific volumes several years in advance. Yet such systematic planning and contracting appears to be missing to date, thereby placing enormous power and pressure onto companies operating transport and storage services. This challenge is exacerbated as more and more private and government actors set net zero targets without having planned their specific steps to implementation, construction and operation of CO₂-capturing hardware.

Third, there is a risk of rent seeking, given the limited competition among storage providers due to the high barrier to entry for sites offering substantial storage capacity. In the medium term, such inefficiencies and windfall profits could unduly keep costs elevated and often passed through to consumers, which may result in negative sentiments. Where windfall profits might be passed onto public budgets, this would risk undermining support for relevant public policies. Possible measures to enhance cost transparency need to be explored to ensure appropriate pricing in the small transport- and storage service markets. Competitive bidding for storage contracts and transparency requirements could to some degree help prevent such rent-seeking, while a widening of the storage supply market would likely also help ensure healthy competition over time.

Further analysis presented in this report will outline possible policy approaches, private sector initiatives and sector-specific strategies that seek to address these barriers and support Switzerland in achieving its emission reduction targets.

Analytical framework – development of policy instruments and private initiatives

This section outlines the analytical framework applied in this analysis and explains how policy instruments and sectors are analysed in this report.

Policy instruments and private sector initiatives – categories and introduction

For the purposes of this paper we understand ‘policy instruments’ to mean a legal, institutional or otherwise government-driven measure or practice that allows achieving a profitable business case for CCUS activities. Policy instruments outlined in subsequent chapters that could target CCUS include:

- instruments enhancing the attractiveness of private investment by moderating risks of uncertain future (carbon) revenues;
- public coordination for the development of transportation and storage infrastructures;
- compliance market generation (ETS and international carbon markets under the Paris Agreement)²;
- regulation via sector agreements and the modification of importer's compensation obligation; and
- direct government funding and public procurement, among others.

The levers such measures would pull to bring CCUS projects into being can be grouped in four dimensions, although individual policy instruments and private sector initiatives overlap in their functions (see Figure 1). Some policy instruments are even intertwined. This could happen, for example, when one instrument generates revenue for a government entity or a dedicated fund, which can then be dispersed through another instrument as is the case for the EU ETS providing funding to be dispersed by the Innovation Fund.

² CDR projects are in principle eligible in the CH compliance market since 2022 through the compensation scheme (Kompensationsprojekte in der Schweiz – see www.admin.ch), but CCUS projects have not yet emerged as a successful project type.

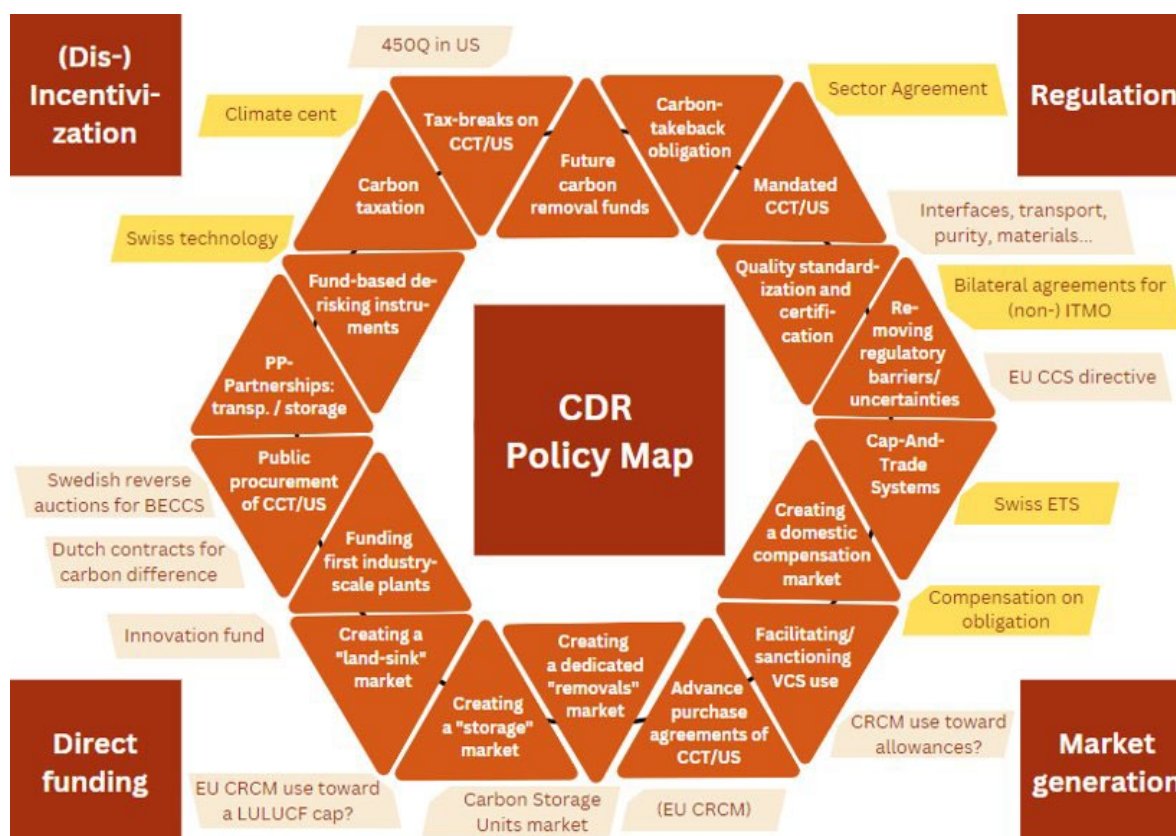


Figure 1: The four levers policy interventions and private initiatives can pull: incentivisation, market generation (voluntary and compliance), regulation and direct funding; instruments most relevant for Switzerland are highlighted in yellow.

Source: the authors (2023)

Figure 1(above) shows examples of policy instruments and private initiatives that apply in certain regions or to particular value chains. These may serve as inspiration in other contexts, potentially with requisite modifications to make them fit. The following sections will give a spotlight on each of the four corners as a starting point with more detailed explanation of respective policy instruments pertaining to each group presented in Section 4.

(Dis-)incentivisation instruments

(Dis-)incentivisation instruments enhance the financial attractiveness of CCUS activities. In contrast to direct funding, such measures are not necessarily tied to a specific project being implemented and some are not conditional to the actual delivery of carbon results. Examples of policy approaches and initiatives in this group include:

- tax breaks and other fiscal measures;
- mitigating revenue uncertainty from carbon price fluctuations through e.g. contract-for-difference including fiscal instruments that adapt to carbon pricing fluctuations, or sector pooling to top-up (voluntary) carbon market revenues; and
- public-private coordination and cooperation on transport and storage infrastructures.

Regulatory instruments

Regulation can be used to compel the use of CCUS by particular actors (polluters, financial actors) or to complement financial incentivisation instruments. Examples of policy approaches and initiatives in this group include:

- expanding the scope of existing sector agreements for long-term and scaled commitments to the development and operation of CCUS value chains, or the introduction of new-sector agreements including obligations to remove or store CO₂;
- regulatory changes to make investments in CCUS attractive;
- regulating the financial sectors to align financial flows to climate targets; and
- regulating public procurement (on state purchases of products or services).

Market generation instruments

Market generation pursues the development and advancement of carbon-results-based incentives via either a compliance demand (in ETS or Paris Agreement carbon markets) or by leveraging voluntary demand by private actors seeking to compensate emissions or make contribution claims towards accelerating decarbonisation. Example of policy approaches and initiatives in this group include:

Policy measures to generate and/or utilize market based instruments

- Domestic offsetting
- Piloting of bilateral Article 6.2 transactions (for CCUS projects abroad and with cross-border components)
- Expanding the scope of the Emissions Trading System

- And accelerating the readiness of new sectors for ETS inclusion

Private initiatives to unlock (voluntary) carbon market demand

- Mobilising conventional voluntary carbon market demand for new CCUS project types
- Sparking Advance Market Purchase Agreements to overcome investment risks through voluntary private sector support
- Measures for accelerating private sector preparedness for ETS inclusion

Direct funding instruments

Direct funding involves the payment upon delivery of a specified volume of carbon emissions reductions or removals. In contrast to incentivisation and carbon market generation, direct funding is tied directly to the results of a specified mitigation volume or the meeting of a pre-specified development milestone. Examples of policy approaches and initiatives in this group include:

- direct provision of funds for pilot and demonstration projects; and
- public procurement of CCUS credits.

While many of the listed policy examples represent governmental policies, private initiatives can be very important enablers or complements of public policy measures. This includes in particular, measures that complement market-generation instruments, including tapping into the potential of the voluntary carbon market (VCM) and mobilising demand both domestically and internationally for mitigation units from CCUS activities, which have so far been underdeveloped. The use of advance market purchase agreements, which represent a combination of a market generation and direct funding instrument, has been particularly relevant in sparking carbon-dioxide-removal (CDR) activities and could become increasingly relevant for CCUS activities in general with the development of comprehensive project methodologies for VCM transactions.³ Another avenue for private sector efforts can be via public-private partnership (PPP) ventures.

Although these policies are considered in the report one by one, successful national strategies often include instruments that include several of the four elements by combining the most appropriate policy measures at the appropriate time for the CCUS value chains.

³ Such as Frontier – set up by Stripe, Alphabet, Shopify, Meta, and McKinsey aiming to accelerate the development of CDR by guaranteeing future offtake up to 2030 – or NextGen, which brings together leading companies from across Asia, Europe and North America to buy over a million tonnes of technological carbon removals by 2025.

Sectors

There are unique challenges and opportunities for each step in the CCUS value chain. Additionally, there are differences between sectors that must be considered to consider suitable instruments that can be applied to them. Only joint analysis of the potential of each policy measure and the specific sectoral characteristics can result in a well-informed CCUS support strategy.

The three sectors analysed in this report (solid waste, liquid waste and cement) were chosen because they offer opportunities for demonstrating CCUS value chains in the near future. Further analysis of these sectors will also shed light on challenges and opportunities facing other sectors. We will introduce their potential for CCUS scale-up in general, as well as their suitability for the specific demonstration projects covered by the DemoUpCarma project.

Policy instruments and private sector measures

The policy instruments and private sector measures included in this section represent those policy options which have the potential to support the Swiss ambition in further developing and upscaling CCUS solutions. As discussed in the briefing note preceding this report, the most promising identified policy options can be listed under the incentivisation and the market generation policy areas shown in Figure 1 (above). Nevertheless, they can be complemented with new or expanded instruments in the categories of direct funding and regulation. The full list of instruments selected for analysis in this section is shown in Table 5 (below).

Table 5: Selected policy instruments

Policy
Incentivisation
Carbon-price floor inducing instruments: CfDs, industry sector pooling for carbon pricing top-up, and carbon-price adjusted tax breaks
Public-private coordination and cooperation on transport and storage infrastructures
Market generation (towards compliance or voluntary carbon markets)

Advance purchase agreements in compliance or voluntary carbon markets

Domestic offsetting for compliance with the compensation obligation

Inclusion in ETS compliance

Inclusion in International compliance carbon markets

Regulation

Sector agreements

Direct funding

Direct funding

Public procurement

Source: the authors (2023)

While most of the policy instruments discussed in this document are government led, the private sector's engagement for the development of policy support instruments is essential for their economic viability. This refers both to the advisory role for policy development as well as supporting governmental policies with private sector-led initiatives. Each of these policies are discussed further in this section.

Incentivisation

Carbon-price-floor-inducing instruments: CfDs, industry sector pooling for carbon pricing top-up and carbon-price-adjusted tax breaks

One of the largest barriers CCUS projects face is the uncertainty with regards to sufficiently high carbon prices in the future. The lengthy payback period of multiple decades hinders private actors from engaging in CCUS projects due to the large risk of insufficient future revenues which would make the project unviable. To address this, a number of de-risking instruments could be developed, including those applied by private sector actors. These instruments help to effectively achieve a minimum or fixed carbon price either through measures that complement carbon market dynamics or fiscal measures.

One such measure is CfD, which can act to provide either a price floor or a price stabiliser (Rilling et al., 2022). In the former case, the government provides a one-directional intervention which comprises a top-up should the carbon market price drop below a pre-arranged price level. In the latter case, however, the interaction could go both ways requiring market participants to pay into a fund should the price exceed a particular level, thus creating a price corridor. CfDs are already being implemented for CCS projects in the Netherlands.

For CfDs to function effectively, a wider market is needed. CfDs could be introduced to complement the Swiss and EU ETS carbon price for specific sectors or project types, serving as a planning security that allows for calculating the viability of a project with a fixed carbon price. However, companies benefitting from CfDs have fewer incentives to be competitive in the trading system. As the core idea of the EU ETS is based on the principle of cost-effective and economically efficient emission reductions, price guarantees from CfDs could undermine free market price formation (EEX, n.d.). Due to these possible interferences, the impacts of such a mechanism on the ETS carbon market would need to be assessed prior to the potential implementation.

There may also be opportunities for industry sector associations to voluntarily pursue a pooling approach to stabilise incentives. This can be done by, for example, complementing a sector agreement mandating the development of a particular number and volume (measured in tCO₂) of CCUS activities. Under this scenario, funding can be pooled from all sector participants to support the development and operation of the required installations and utilise such funds to top up any gaps between pre-determined expenses and any carbon revenues accruing. This would distribute the benefits and risks of fulfilling a regulatory sector-wide mandate among all actors.

Taxation-based incentives could also complement carbon market revenues. The most notable example of a tax incentive for CCUS is 45Q⁴ in the US, providing tax credits to companies that capture and/or permanently store a certain amount of CO₂. If such tax incentives are set at a fixed level, they

⁴ 45Q refers to a United States federal tax incentive that provides financial benefits to companies or entities that capture and store CO₂ or utilize it for enhanced oil recovery purposes, aiming to incentivize CCUS technologies.

would be considered a form of direct funding. However, such fiscal measures could also be designed to cushion carbon-price fluctuations if they are set to achieve a minimum incentive level – as a function of and complementing carbon market prices. This in turn would help achieve a particular predefined revenue level necessary to pay back CCUS investments.

Table 6: Carbon price floor inducing instruments

Instrument	Carbon price floor inducing instruments: CfDs, industry sector pooling for carbon pricing top-up, and carbon-price adjusted tax breaks
Description	Policy instruments which can mitigate the impact of price fluctuations for CCUS projects.
Successful application example	CfDs
Timelines	Medium term
Potential implementation agents	Government; private sector (sector associations)
Potential impact	Emissions Significant impact on emission reduction via a straightforward incentive to project developers and investors Economic Increased public spending or reduced public revenue and hence pressure on the public budget
Swiss context	The KIG could potentially offer opportunities to move toward a de-facto price floor or guaranteed price for some specific types of activities or services for example via its Article 6 (if para 4 is interpreted to assurance of additionality, to be ensured via an additionality test), via its Article 10 (where federal and cantonal governments can set prices for the units they purchase), or via the agreements with the financial

sector provided for in its Article 9, para 2.

Main advantages

- Straightforward signal to project developers and investors
 - Simplicity of implementation
-

Main risks and challenges

Pressure on the public budget, could be on the order of 50CHF/tCO₂

Source: the authors (2023)

Public-private coordination and cooperation on transport and storage infrastructures

Transporting solutions and the necessary infrastructure will be crucial for scaling of CCUS projects. Their development will often require a coordinated national and international dialogue and will need to be led or strongly supported by governments. Experience in this type of cooperation can be leveraged from the market and regulatory structures used for the development and operation of natural gas, water and electricity supply infrastructures.

For this purpose, federal mandates could be allocated to i) coordinate and regulate the development of national CO₂ transportation and storage infrastructures; ii) engage in international negotiations and engagements regarding the linking of EU and Swiss pipeline infrastructures; and iii) regulate the operation of these infrastructures. Given the decentralised mandate of CO₂ transport and storage infrastructures at the cantonal level in Switzerland, this challenge calls for a cooperative approach involving both federal and cantonal authorities leveraging the provision of risk-capital per Art. 7 as a means to de-facto contribute to a cooperative approach. Collaborative efforts between these entities are crucial to align development and operation of interconnected infrastructures (e.g. transport). The federal government may voluntarily facilitate cooperation among cantons willing to engage in such a manner as the provision of access to sufficient storage (Article 3. para 5) also requires coordinated provision of necessary transport means.

The engagement on the European level related to the transport and infrastructure can be taken further by balancing supply and demand in storage capacities and streamlining the permitting processes for accelerated rollout of key projects, similar to the way it was done in the case of, for example, the Projects of Common Interest in the EU. It will also be necessary to support incentivising scaling along the entire value chain (e.g. building transportation barges and ships), which to an extent can be done through advance purchase agreements, however, other more targeted incentives may be necessary once bottlenecks for scaling of specific projects are identified.

Table 7: Public-private coordination and cooperation on transport and storage infrastructures

Instrument	Public-private coordination and cooperation on transport and storage infrastructures
Description	National and international dialogue to support development of transportation and storage infrastructure, as well as regulating transportation and storage activities to ensure fair access and efficient operationalisation.
Successful application example	Water and electricity supply infrastructures in the EU

Timelines	Medium to long term
Potential implementation agents	Federal and canton governments
Potential impact	Emissions Significant as insufficiently developed transport and infrastructure solutions can significantly slow down the development of CCUS solutions Economic Will require significant investments, yet the costs and benefits can be shared within the country and internationally
Swiss context	A working group comprising representatives from cantonal administrations was established by Federal Office for the Environment (FOEN) in September 2022 to address the long-term legal framework issues and the split of responsibilities between the cantons, the Swiss federal state and the private sector in enabling CCUS activities.
Main advantages	Joint problem solving from technical, efficient and innovative performance of the private sector and regulatory oversight and public accountability of the government
Main risks and challenges	• Requires coordination on the federal and international level which can be challenging • Requires significant buy-in from both public and private sector and associated infrastructure investments

Source: the authors (2023)

Market generation

Advance purchase agreements in compliance or voluntary carbon markets

For some forms of CCUS, the costs are projected to remain higher than the carbon revenues that can be reaped from established carbon markets, such as ETS, voluntary, domestic or international compliance markets (i.e. those under Article 6 of the Paris Agreement). While the carbon-price developments are uncertain and will depend on the supply-demand balance, their level is at least in the short to medium term insufficient to incentivise CCUS projects without further support. These technologies would thus not participate in carbon markets in the near term under the existing conditions.

Private sector initiatives have thus sought to target these high-cost measures, especially towards technological carbon dioxide removal with high permanence to ride down their cost-curve and make affordable removals available later on (perhaps in anticipation of more stringent regulation that would otherwise impose very large cost). Over the last years, there were multiple coalitions and groups of private companies, often alongside national governments, who pledged to contract certain amounts of credits from technological carbon removals in the coming years. Examples of such groups include Frontiers, the advanced CDR market commitment, the Next Generation carbon removals facility, or Swiss Re's and Climeworks' multi-year carbon removal purchase agreement.

While so far such initiatives have been primarily led by the private sector, they can also be driven by the public sector actors. The US Department of Energy, for example, announced that it intends to purchase direct air capture (DAC) credits from the DAC hubs that are currently being developed. Similarly, the City of Zürich announced a call for tenders for the management of the transport and permanent storage of 20,000 tonnes of biogenic CO₂ per year from its sewage sludge incineration plant (Stadt Zürich, 2023). Based on a feasibility study which has shown that a plant could be built to capture and liquefy CO₂ at a price point of CHF 210 to CHF 290 per tCO₂. The tender process is now seeking to determine the additional costs for transport and storage, while the city of Zürich is seeking a long-term contract with CO₂ off-takers for 10 years. Although still at an early planning stage, the tender indicates a general interest of the public sector in driving CCUS technologies forward.

Such initiatives are crucial for the high-cost technologies to undergo maturation and for their costs to come down. To advance and scale these continually, however, they will need to be met at some point by adequate carbon-revenue-generation opportunities in established voluntary or compliance markets which would likely only be able to happen once their costs come down sufficiently. Therefore, it would be beneficial in the short to medium term to seek such technology-specific advanced commitments while monitoring the interest and demand for CCUS projects in the voluntary and compliance markets as their costs come down.

Table 8: Advance purchase agreements in compliance or voluntary carbon markets

Instrument	Advance purchase agreements in compliance or voluntary carbon markets
Description	Acquisition by private companies of emission reduction units generated via higher cost CCUS technologies
Successful application example	Frontiers; the advanced CDR market commitment; the Next Generation carbon removals facility; multi-year carbon removal purchase agreement between Climeworks and several companies such as Swiss Re, UBS, BCG and Microsoft.
Timelines	Short-term: Immediate source of carbon revenue for various CCUS value chains (i.e. 2023 onwards) with long-term availability horizon
Potential implementation agents	Private companies, potentially with support from the government
Potential impact	Emissions: High transformational impact through supporting the maturation of more expensive technologies Economic: Lower negative economic impact on participants given the voluntary nature of agreements (e.g. companies can decide whether/when they have available finance to enter such an agreement) Allows attracting international private carbon finance to higher cost CCUS technologies
Swiss context	Swiss companies engaging in advanced purchase agreements further stabilises the demand of CCUS and represents an opportunity for Switzerland to strengthen its leadership in supporting CCUS

technologies.

Main advantages

- Immediate source of finance
 - Attracting private international carbon finance (e.g. lower impact on national taxpayers)
-

Main risks and challenges

Given the voluntary nature may not provide sufficient financing to priority technologies

Source: the authors (2023)

Domestic offsetting for compliance with the compensation obligation

The Swiss CO₂ Act⁵ obliges importers of fossil fuels to compensate for resulting emissions. The KliK Foundation facilitates the fulfilment of the legal obligation of fossil fuel importers. The foundation acts as an intermediary between fossil fuel importers and domestic emission-reduction projects that generate offset credits. The foundation buys the offset credits from the approved projects and sells them to fossil fuel importers to offset their carbon emissions. The funding volume in 2021 amounted to over CHF 200 million for Swiss projects. Eligibility criteria are set by the Swiss Federal Office for the Environment (FOEN). The foundation's involvement in the market helps to support the development of domestic emission-reduction projects and promotes the use of offset credits to reduce greenhouse gas emissions in Switzerland.

As of changes to the CO₂-Ordinance in June 2022⁶ CCUS projects with long-term storage in biological, geological or storage in non-organic building materials (e.g. concrete) are eligible to generate carbon offset credits under the Swiss domestic compensation scheme. According to Article 5 paragraph 1 letter a, only project types that are not explicitly excluded in Annexes 2a (projects abroad) and 3 (projects in Switzerland) are eligible (FOEN, 2022). Furthermore, projects abroad are only eligible, if Switzerland has established a bilateral climate agreement with the country in which the project is planned to take place.

This was an important step towards creating demand for CCUS emission-reduction-generating market, however, current prices for such projects are far above the usual price level the KliK foundation is paying. To ensure sufficient support for CCUS activities, despite high-cost levels, a quota could be imposed on the current fuel importers' compensation obligation. This would ensure

⁵ CO₂-Act, SR 641.71: <https://www.fedlex.admin.ch/eli/cc/2012/855/en>

⁶ CO₂-Ordinance, SR 641.711: <https://www.fedlex.admin.ch/eli/cc/2012/856/de>

that a certain part of the compensation would have to come from CCUS projects. The annual increase in the quantities of emissions to be offset would then also affect the quota and ensure predictable financing for the CCUS sector. The quota would not dictate investment decisions for CCUS projects, but it would serve to guarantee a growing source of revenue potential for those ready to deliver CCUS-based mitigation results. The financing solutions outlined in this paper could be considered as partial measures towards facilitating the implementation of CCUS projects. It is crucial to acknowledge that even small-scale CCUS projects require substantial investments for relatively modest emissions reductions and/or removals.

Additionally, KliK's predecessor, the Climate Cent ('Klimarappen') Foundation⁷ in 2022 contained unused funds of approximately CHF 50-70 Million after its closure in 2012, which the foundation then was mandated to leverage for supporting mitigation projects domestically and internationally, including for CCUS activities (UVEK, 2022a). The sponsorship agreements, totalling 50 million Swiss francs, were officially announced in late August 2023. All these initiatives are focused on CO₂ capture on biogas facilities in Switzerland. Among these projects, three focus on the utilisation of CO₂ into Swiss construction materials, while the remaining two are dedicated to transporting CO₂ abroad for secure underground storage⁸.

In addition to the adjustments made to the Swiss compensation scheme to render CCUS projects eligible, the challenges associated with the previously mentioned price per ton, combined with limited planning predictability, present significant barriers that impede most CCUS projects from making investment decisions. This legislative framework which enables the mechanism of the Swiss compensation scheme is in force until the end of 2030, with currently no follow-up legislation in place. Without subsequent legislation, fuel importers will no longer be bound to offset their emissions from 2031 onward. Consequently, project developers are left with no assurance that this revenue stream will continue to exist. The lack of certainty regarding the sale of carbon credits under the Swiss compliance scheme significantly diminishes the appeal of CCUS project development. Such projects entail substantial upfront investment costs and correspondingly extended amortization periods, making them especially unattractive under these circumstances.

Table 9: Domestic offsetting for compliance with the compensation obligation

Instrument	Domestic offsetting for compliance with a compensation obligation

⁷ The foundations' mandate: <https://www.newsd.admin.ch/newsd/message/attachments/71468.pdf>

⁸ Mitigation project overview: <https://www.klimarappen.ch/en/Negative-emissions-technologies-.1.html>

Description	A policy instrument for compensation of fossil fuel importer's emissions through partially Swiss mitigation projects; As of 2022 eligible project types include CCUS.
Successful application example	KliK's predecessor (Climate Cent Foundation) had a call for tenders for carbon projects in the areas of negative emission technologies and CCUS in 2022, totalling to 50 million CHF distributed among five projects.
Timelines	Medium term: depending on • KliK's mandate to pursue CCUS project types and availability of sufficient funds from the fossil fuel compensation obligation. • Follow-up legislation after 2030
Implementation agents	Government imposing the offsetting obligation
Potential impact	Emissions Emission reductions or removals depending on matching price levels of up to CHF 160/t CO₂. This is the level of the fee to be paid in case required mitigation levels are not met Economic • Funded through the compensation obligation of fossil fuel importers managed by the KliK Foundation. The cost is likely to be transferred to fuel consumers. • CCUS credits may tend to be more expensive than other project types and thus require the introduction of a regulatory mandate to provide a specific share of results based on CCUS (thus inducing price differentiation).
Swiss context	The fossil fuel importers have an obligation to compensate for emissions. The compensation scheme supports CCUS project types, however, there is no compensation obligation with CCUS offset credits

Main advantages

- The mandate and practice for domestic compensation are already in place and are continuously increasing the compensation obligation.
- Lessons could be drawn from the Klimarappen Foundation call for proposals in 2022.

Main risks and challenges

- Insufficient price levels and high up-front funding requirements of individual CCUS projects
- Increase of fuel prices for consumers as the additional costs are passed on to them
- No follow-up legislation in place after 2030
- Political uncertainty could undermine the continuity of the funding commitments

Source: the authors (2023)

Inclusion of the relevant sectors and their CCUS options in ETS compliance

While governmental support and voluntary carbon markets can to an extent support CCUS technologies, in the long term a strong demand from the private sector will be needed. The current provisions of the EU ETS do not provide adequate incentives for companies covered by the scheme to engage in CCUS activities. As of today, only the transportation of CO₂ through pipelines, which are not yet established, is considered eligible for CCS initiatives. However, the proposed reform within the EU ETS aims to broaden eligibility to include all modes of transport (e.g. by ship or truck)⁹. Implementing these reforms would significantly improve the situation for companies that are currently constrained in their actions. Moreover, these same companies face limitations in participating in CCUS projects to generate carbon credits under the VCM. Existing carbon standards prohibit the monetisation of reductions already covered by any form of carbon reduction scheme.

The inclusion of all modes of transport within the EU ETS would unlock opportunities for CCUS activities among currently covered entities, such as cement plants and other fossil-based point sources of CO₂. However, to provide further incentivisation, it is advisable to extend CCUS attractive sectors within the EU ETS. The EU Commission will assess in 2026 the possibility of including municipal waste incineration in the ETS, which would pave the way for including it from 2028 onwards. In addition to that, regulatory changes in the ETS are required to fully include biogenic sources from waste incineration plants as well as from Bioenergy with Carbon Capture and Storage (BECCS) and DAC facilities in the EU ETS. Such regulatory changes could allow the respective entities to receive free

⁹ See proposal text, p. 36: [pdf \(europa.eu\)](https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023PC0033&from=de), Retrieved 20.04.2023

allowances in the future, which could subsequently be sold to other actors within the system. If this modification was done in both the EU and the Swiss ETS's, it would serve as a strong incentive for BECCS. If the scope of the ETS was expanded to include the waste sector, then the capture and storage of both biogenic and fossil CO₂ from waste incineration including sewage sludge incineration would be incentivized. In such a case, the EU would need to make sure that an ETS incentivisation for BECCS is in line with its Effort Sharing Regulation in a way that biomass emissions are not double counted.

Currently, the burning of sustainable biomass is considered to be emission-free, assuming that the emitted GHGs have been filtered from ambient air and that the biomass is immediately replanted (hence the term *sustainable*). This view implies that not only a distinction between biogenic and fossil waste but also between sustainable and non-sustainable biogenic waste would need to be considered, as capturing emissions from sustainably grown biogenic waste would need to be counted as an emission removal.

Moreover, neither the EU nor the Swiss ETS is currently recognising emission reductions or removals in products. The proposal for the EU ETS reform, however, includes CO₂ storage in products where it is permanently chemically bound "so that they do not enter the atmosphere under normal use and any normal activity taking place after the end of the life of the product". According to the Message for Revision of the CO₂ Law (Botschaft zur Revision des CO₂-Gesetzes für die Zeit nach 2024,) Switzerland will follow the EU's approach to include durable storage in long-lived products in its latest revision (Schweizerischer Bundesrat, 2022).

Defining what permanence means will be key in the discussion on recognizing carbon stored both in products and in geological formations when mitigation results involving CO₂-storage become tradeable against an emissions cap. If a certificate for "traditional" (i.e., not related to carbon capture) emission reductions have the same value (i.e., allowance price) as a certificate generated via CCUS, then both need to deliver the same product (i.e., less CO₂ in the atmosphere). This condition is only fulfilled if captured carbon is stored for sufficiently long (geological, i.e. at least 100 year) timescales.

Nevertheless, for the ETS to consistently enable CCUS, regulatory changes are necessary but not sufficient. The price level of traded allowances on the ETS market needs to be higher than the cost of CCUS operations. This can be challenging as even the growing carbon prices established on the EU ETS market reaching 100 EUR/tCO₂, may not be sufficient and uncertainty over future price levels is problematic given the multi-decadal nature of most CCUS investments. Therefore, incentives through the Swiss ETS may only become relevant over time when (subsidised or otherwise supported) infrastructure investments have already brought down costs of CCUS, while scarcity in the ETS market has driven up allowance prices. At the same time, given the need for regulatory changes for the systematic inclusion of CCUS credits in the EU and the Swiss ETS, it may be important to start examining possible pathways in anticipation of such future opportunities.

Broadening the scope of the ETS to recognize removal results based on biomass-carbon captured and stored would increase the number of certificates in the system, though enlargening the scope to include new sectors would also offer an opportunity to set an appropriate cap. An increase in supply (unless the cap is adjusted accordingly) could lower allowance prices and incentives to reduce emissions. While the (net-)cap would be reached at overall lower allowance prices, the increase in

CCUS and CDR facilitation would not lead to additional reductions/removals. An adjustment of the cap could be used to ensure the reductions/removals realised via CCUS come “on top” of the ETS’ cap for “traditional” reductions.

An alternative pathway for the Swiss and the EU ETS to provide incentives for CCUS projects, is through crediting of CDR – separately to the ETS itself. The EU is currently developing the regulatory basis for recognising removal credits. And while it is unclear how these would be used in the future, one option might be that they are allowed to be traded against ETS allowances. The EU is currently going through an extensive consultation process, to outline the key structures of the framework, but the decision of how it will be put to use will not be taken in the near future. However, once the mechanism is in place (possibly in 2025) and should the ETS regulator decide that the certified CCUS credits can be used towards EU ETS, it would be likely that this would coincide with other major revisions in the ETS that affect the supply-demand balance (see discussion in preceding paragraph).

With the requisite willingness to expand coverage to new sectors and to also include biomass-processing installations, the ETS policy instrument has significant potential for creating a long-term incentive for CCUS activities. Such a demand-driven incentivisation is key and would complement the many supply-push focused and often subsidy-driven (short-term) policy instruments that are currently being considered. However, given the scale and complexity of the ETS policies, the necessary changes would only be implemented in the medium to long term. Therefore, it is crucial to start considering these changes early on and work on improving the readiness for CCUS inclusion in ETSs as soon as possible.

Table 10: Inclusion in ETS compliance

Instrument	Inclusion in ETS compliance or allowing removal credits to be sold into ETS
Description	Systematic inclusion of all CCUS sector participants under the ETS – including those solely processing biomass – to create monetisation opportunities from sale of allowances. Alternatively, allow the sale of removal credits to entities under the ETS to allow them meet their cap.
Successful application example	ETS coverage of cement plants or power and heat generation from fossil-thermal power plants (and associated CCS activities) – though price levels have been insufficient to date.
Timelines	Long-term: the costs of CCUS solutions likely would need to reduce before their inclusion in EU ETS can become reasonable.

Potential implementation agents	EU Commission and Parliament; Swiss Parliament and Federal Office for the Environment (FOEN) administering the Swiss ETS

Potential impact	Emissions Significant long-term effect through creation of demand from the private sector Economic • Ability to direct private sector finance to CCUS solutions • The need to wait for CCUS project cost reduction, or provide a subsidy to top up the ETS price

Swiss context	While the Swiss and EU ETSS cover emissions from industrial sectors as well as power and heat generation from fossil-thermal power plants (and associated CCS activities), biomass power plants are not covered. A modification of both ETS could allow for the incentivisation of BECCS if biomass-based power plants were included and received free allowances that could be sold to other actors subject to the ETS.

Main advantages	• Inducing demand for removal credits including those generated via CCUS activities • Ensuring efficiency through markets • Ensuring widening the incentives by including additional actors in the ETS scope

Main risks and challenges	• Currently price levels would not be sufficient • Likely a significant lead-time for the EU (and Switzerland) to adopt such fundamental modifications to the ETS scope • Inclusion would increase number of available certificates on the market, thereby decreasing the price and incentives to

reduce/remove emissions (unless the cap is adjusted accordingly)

- Criteria and requirements for storage permanence and biomass sustainability as well as respective MRV standards need to be defined in a way that does not jeopardise environmental integrity

Source: the authors (2023)

Inclusion in international compliance carbon markets

Switzerland is one of the countries which stipulated that part of the emission reductions foreseen in its Nationally Determined Contribution (NDC) will be achieved through funding projects abroad. To this end, the country is establishing several bilateral Article 6.2 agreements to source the necessary mitigation outcomes. The Foundation for Climate Protection and Carbon Offset (KliK), which is mandated by the government to acquire Internationally Transferred Mitigation Outcomes (ITMOs) to achieve Switzerland's NDC, could therefore further support compensation activities and Article 6 CCUS cooperation.

Furthermore, the Swiss Climate and Innovation Act approved in June 2023 (Bundesgesetz über die Ziele im Klimaschutz, die Innovation und die Stärkung der Energiesicherheit (KIG)), requires net-zero emissions in Switzerland in 2050 (and in the government in 2040). The law will increase demand for negative emissions substantially. The negative emissions can be generated in Switzerland or abroad through international carbon markets, e.g. under Article 6.2 or Article 6.4 of the Paris Agreement.

While this policy instrument is in many ways similar to the public procurement of carbon credits discussed below, its main difference is that it allows the establishment of bespoke bilateral or multilateral agreements with countries from which Switzerland intends to purchase credits in the future to clarify the guiding rules of such transactions. Additionally, Article 6.2 cooperation can help only to finance the projects through provision of carbon finance (as public procurement would be) but also to provide other types of bespoke support for example by purchasing credits not for declaring an offsetting claim but rather for the sake of having supported climate action with clearly quantified results (as credits are retired).

Since Switzerland has already become the first country in the world to undertake an ITMO transaction and has ongoing Article 6.2 cooperation preparations in several other countries, the timeline required for the implementation of this policy solution would in many ways depend on the readiness of the transferring country to engage in Article 6 cooperation and project readiness.

Besides agreements signed with other countries, the Swiss government has also signed non-binding MoUs with Iceland and Norway to further accelerate the development of CCUS and CDR and Switzerland appears in continued exchange with potential partner countries to clarify outstanding questions such as where is a mitigation result achieved, under which circumstances does an

international transfer occur, and how do the different involved parties account for and report the results consistently. While contractual uncertainties at the level of private entities involved in such transactions prevail and some additional clarifications remain to be achieved at the state level , Switzerland's early and decisive action sets an encouraging tone for negotiating and eventually including national and transboundary CCUS and CDR activities – including where applicable under Article 6.

Article 6 represents one vehicle to further cooperate, finance and implement CCS and CDR-relevant projects on a global level. For this purpose, it will be important to initiate CCUS transactions of ITMOs as soon as possible to give a push to the inclusion of the CCUS emission reductions in Article 6 activities. Some preparatory steps will be necessary for this purpose, including the analysis of lessons learnt from the advance purchase agreements, convening and initiating the dialogue with key stakeholders and helping develop the country's arrangements for large CCUS hubs. It will also be necessary to finalise the Article 6 readiness steps not related to CCUS, such as development of insurance solutions for ITMO flows, as this work will give greater confidence to all actors involved in the Article 6 CCUS discussion.

Given the early stages of this process, the two mechanisms of Article 6 (Article 6.2 and 6.4) can play different roles. The more flexible, bottom-up nature of Article 6.2 cooperation and its accounting framework could be especially relevant for early action and pioneering activities. This multi-country cooperation under Article 6.2 will become even more important when assuming that an increasing number of CCS hubs, clusters and networks will be built in the future. Given that Switzerland became the first country in the world to execute an Article 6.2 ITMO transaction, it is well positioned to lead by example and include the increasing volumes of CCUS carbon credits in the bilateral cooperations it is currently establishing to source mitigation outcomes towards its NDC target.

Collaboration under Article 6.4 on the other hand, will likely take some more years to be fully operational. Article 6.4 activities are, due to their setup and top-down nature, generally seen as of higher quality than comparable Article 6.2 activities, which could eventually also result in higher premium prices for such credits. That said, the more innovative projects which may not yet be suitable for Article 6.4 transaction, could also fetch high prices. For such projects, development and approval of carbon crediting methodologies will be needed, for which public funding would likely be required.

Table 11: Inclusion in international compliance carbon markets

Instrument	Inclusion in international compliance carbon markets
Description	A policy approach which would comprise several steps directed to enable the use of CCUS mitigation outcomes to be transferred under the framework of Article 6 of the Paris Agreement

Successful application example	Switzerland's collaboration with Iceland and the Netherlands specifically addressing CCS and CDR, including potential Article 6 transactions
Timelines	Medium to long-term: given that Switzerland has already undertaken its first ITMO transaction, the inclusion of CCUS in Article 6.2 cooperation can be executed relatively fast.
Potential implementation agents	Government (main actor for Article 6.2 cooperation and an enabling actor for Article 6.4 cooperation)
Potential impact	Emissions Potentially significant impact which at least in the short-term will depend on Switzerland's Article 6.2 ambition, the priority of CCUS solutions in comparison with other climate change priorities, and availability of suitable CCUS cooperation opportunities Economic • Article 6.2 cooperation would need to be funded from the public budget • Article 6.4 cooperation will be able to attract private carbon finance, yet the demand levels may be hard to predict
Swiss context	Switzerland is one of the pioneering actors in Article 6 cooperation and is extremely well placed to advance the global discussion on the inclusion of CCUS solutions in Article 6 cooperation, including leading by example.
Main advantages	• Allows to accelerate CCUS participation in Paris Agreement cooperation • Will help to eventually start attracting private finance to CCUS projects via Article 6.4 mechanism

Main risks and challenges

The demand from the private sector for such solutions is hard to predict

Source: the authors (2023)

Regulations

Sector agreements

Where they do not result in double-incentivization overlapping with an ETS cap, regulation-based mandates to pursue CCUS through sector agreements could take various forms. One is the mandate for the sector as a whole to achieve construction and operation of CCUS on a growing share of each sector's installations. The main advantage of this instrument is its relative simplicity, clear requirements and timeline, which provide regulatory certainty to the CCS project developers as well as the government allowing them to plan the pace and scale of CCS project development.

Downsides include significant transaction costs and the need for strong coordination within the sector as well as the likely absence of a long-term incentive. As a result, implementation of such agreements can face sector-specific challenges whereby sectors with high international competition and low margins are likely to push back against such mandates. To address these concerns, various policy mechanisms can be applied. These include the provision of government funding (e.g. from carbon tax revenues) to affected companies supporting part of the CCUS installation costs or tax relief measures for climate-related tax obligations or other tax categories. Sector-agreements would likely tend to precede an inclusion in the ETS as double-incentivization is to be prevented.

Another option to alleviate the economic impact on the obligated industries can be the implementation of trade-protection measures such as for example a border carbon adjustment. It would introduce a charge on imports from countries which do not impose similar costly mitigation obligations on the sectors in question. While trade-protection measures might alleviate concerns over international competitiveness, they are typically highly complex and controversial in and of themselves and their implementation can take a long period of time, overcomplicating the original simplicity of a regulatory approach. Therefore this approach would be more suitable in the non-competitive sectors where the market is captive and consumers cannot change suppliers, as is the case for municipal waste- and sewage treatment.

The implementation of the sectoral agreement policy approach has already commenced in Switzerland. The Swiss government and the Swiss Association of Waste-to-Energy Plant Operators, VBSA, signed a sector agreement in March 2022 (UVEK, 2022b) This sector agreement follows up on the emission reduction goals set in 2014, which expired in 2021. It obligates operators of municipal waste incineration plants to construct at least one capturing facility by 2030 with the capacity to capture a minimum of 100,000 tCO₂ per year. To guarantee the success of the agreement, intermediate milestones must be met early between now and 2030. By 2023, for example, in-depth

feasibility assessments must be conducted to identify an incineration plant as the candidate for the installation of a capture facility. The incentive for entering such an agreement was the continued exemption from being subject to the Swiss ETS. This exemption, however, may be revoked if the minimum capture requirement is not reached by 2030 or if intermediate milestones are not met. The agreement also requires the development of a roadmap for the entire sector beyond 2030, which allows exploring options for business models and scaling of CCUS.

While the current agreement covers the waste sector until 2030, there are further steps that can be taken to expand and extend the scope and hence the impact of such policy instrument:

- Consider extending the timeline and scope of the sectoral agreement beyond 2030 and beyond a single plant to allow better planning for the eventual scaling up of CCUS installations;
- Consider complementing the regulatory approach with incentivisation: e.g. tax exemptions for those installations which overachieve their CCUS capture targets;

Table 12: Sector agreements

Instrument	Sectoral agreements
Description	A policy instrument that mandates the construction of CCUS facilities by operators where this is technically reasonable.
Successful application example	Sectoral agreement between the Swiss government and VBSA (implemented in 2022)
Timelines	Medium term: the implementation of such an agreement will typically take over a year to allow time for stakeholder consultations and the necessary legal steps to enable its implementation.
Potential implementation agents	Government
Potential impact	Emissions Clear emission reduction pathway through CCUS solutions Economic Benefitting from the ETS exemption as a whole, it is expected that the

sector will collectively share the financial burden of the initial capture plant. The agreement includes a financial plan for 2025/2026 to clarify the economic impact.

Swiss context

Currently the Swiss government has a sectoral agreement with one sector (waste management).

Main advantages

- Certainty for the government in terms of the pace and scale of the CCUS installation construction
 - Planning certainty for stakeholders in the industry sector
-

Main risks and challenges

- Imposes extra costs on actors in the targeted sectors (in case of VBSA, member organisations (all waste incineration operators) fund the implementation via the association)
 - Without supporting measures can cause significant public backlash due to rising waste disposal fees;
 - Some risk of increased littering due to the high cost of waste-disposal
-

Source: the authors (2023)

Direct funding

Direct funding

One of the most straightforward ways to support the development of CCUS technologies is direct allocation of funding to specific projects or project types (e.g. removals involving storage with high inherent permanence) including through research and demonstration funding. Given the high costs currently associated with some CCUS projects, direct funding can allow demonstrating the first-of-their-kind use cases and allow cost reductions while other policies are being developed.

Once the Swiss climate and innovation law will come into force in 2025, it could enable direct support through its Article 6, via existing funding instruments.¹⁰ It includes a broad federal mandate to provide financial support for innovative technologies helping to achieve the country's climate commitments,

¹⁰ [BBI 2022 1537](#)

on the condition that they are not receiving support from other sources. Further provisions in Article 7 allow offering risk-capital to support public infrastructure necessary to achieve the net zero target. Given the potentially very significant investment needs associated with the build-out of CO₂ transportation infrastructure (such as pipelines and terminals) and their need for long-term revenue guarantees, this could become a crucial instrument and enabler.

If existing climate finance instruments were used to raise funds for direct investments in innovative technologies, further financing options could be adopted to minimise the burden on individual instruments. The first approach would suggest imposing a removal funding obligation on the fossil fuel importers which can be implemented via the introduction of a carbon removal levy. The levy revenue would then be directed to a fund which can be administered for example by the KliK Foundation. Alternatively, through a major modification of the legal basis of the Swiss ETS, a direct funding mechanism could be set up following the example of the EU, whereby the revenues from EU ETS allowances are administered by the Innovation Fund¹¹, which supports innovative mitigation projects. If the revenue of the Swiss ETS could be channelled towards a dedicated fund through the required regulatory change, this would free up some additional resources for direct funding. In September 2023, the Swiss City Council suggested allocating the revenues from the auctioning of emission allowances to support initiatives at Swiss ETS installations, particularly those that play a substantial role in the decarbonization of these facilities (Schweizer Ständerat, 2023).

This approach can be straightforward by channelling public financial support to CCUS value chains and it allows also targeting specific types thereof, including either those that may achieve removals or those that achieve reductions in emissions from point sources. It may, however, not be a sustainable long-term solution and especially at scale. This is because such an instrument would place a heavy budgetary burden as evidenced by the Innovation Funds' oversubscription as of late. Therefore, eventually, it will need to be replaced by other approaches mobilising private finance and may be more suitable as a short- to medium-term measure supporting the promising more expensive CCUS technologies with the view to replace the governmental funding with private sources in the future.

Carbon-contracts for difference are a variant of direct funding, serving as a top-up onto the market-based incentive of the ETS. Such a top-up would be conditional on demonstrating that CCUS activities of entities subject to the ETS would incur costs exceeding the incentive-level induced by the ETS (as prices of allowances remain below the cost-level). In such a manner, a guaranteed minimum revenue-level would much improve the outlook for long-term investments. The primary challenge of such a variable instrument lies in the need for the corresponding (public) funding to absorb ETS market uncertainties, while scaling.

¹¹ The EU Innovation Fund is a financial program established by the European Union to support innovative projects that contribute to the transition to a low-carbon economy. It provides significant funding to projects in renewable energy, energy storage, carbon capture and storage, and other clean technologies to help accelerate their development and deployment across Europe.

Table 13: Direct funding

Instrument	Direct funding
Description	A policy instrument which establishes a fund dedicated to financing novel CCUS projects intending to scale down its activities as technologies mature
Successful application example	EU Innovation Fund
Timelines	Short to medium term
Potential implementation agents	Government agencies at national and sub-national levels
Potential impact	Emissions Emission reductions may be limited in the short term, but is expected to increase as technologies mature and reach scale Economic Requires public funding which would require regulatory arrangements allowing to raise this funding
Swiss context	Switzerland already has regulatory arrangements which can enable collection of financing necessary for establishment of a direct funding mechanism, such as for example the fossil fuel import charges or the Swiss ETS.
Main advantages	• Predictable financing opportunity for eligible projects • Ability to support targeted technologies/projects

Main risks and challenges

- Economic pressure on the national economy
- Lack of supply predictability

Source: the authors (2023)

Public procurement

The public procurement approach represents a policy instrument whereby the CCUS technologies are financially supported by the government, either through acquiring the generated carbon credits or imposing such a requirement on suppliers of goods and services to public entities. This mechanism would create predictable and stable demand for CCUS credits and can give the flexibility to target those technologies which are prioritised by the government. The demand can also be regulated proportionally to the support required to scale up each technology and it can be phased out as the technology matures. This mechanism, however, requires public funding for CCUS credit acquisition which would result in a greater burden for taxpayers.

This mechanism can be implemented via two different mechanisms which are described further.

Procurement of CCUS-based credits. Under this approach, the government commits to acquiring a certain number of carbon credits generated from CCUS technologies to achieve or overachieve its NDC emission reduction target. For example, the Swiss Federal law on climate protection goals requires that the central federal administration must have at least net zero emissions by 2040⁶. The credits acquired from CCUS projects can be used towards such targets and sourced as part of the Swiss domestic offsetting obligation. Alternatively, the financial support provided through the acquisition of credits can be counted as a contribution claim (i.e. without the right to claim emission reduction) turning this mechanism into a results-based subsidy.

This policy instrument can be implemented in various forms, including:

- **Reverse auctions** whereby the government commits to acquiring a certain quantity of CCUS carbon credits from the seller who can offer the lowest price. This approach is being implemented in Sweden with the first auction expected to take place in 2023. The early experience that Sweden is gaining with the application of this policy instrument demonstrated that the design of the auctions and definition of specific criteria which projects will have to meet can require extended time which led to the delay of the auction launch which was originally planned for autumn 2022 (Swedish Energy Agency, 2022).
- **Standard tendering process** for the provision of CCUS credits with clear selection criteria: e.g. inherent durability, innovation potential/net zero compatibility, additionality, and coverage of all sectors.

- **Multi-year advance purchase commitment** for nascent technologies, such as for example Direct Air Carbon Capture and Storage (DACCS), which is based on the same mechanism as the voluntary advance purchase agreements, with the difference being that the government would act as a buyer of the generated credits.

Public procurement of goods and services with conditions. Another type of public-procurement-based incentivization is the introduction of a requirement for public administrations to only procure certified carbon-neutral goods and services, which use CCUS (e.g. carbon-free cement using CCS or cement that permanently stores CO₂). This would align with the goal set out in the KIG of achieving climate neutrality in federal government operations by 2040. Implementation of this approach would need to be gradual, as the supply value chain of such products would need to adjust and potentially new qualities of construction materials need to be standardized. Therefore, some flexibility will be needed to phase in this approach using for example a sufficient lead-up period.

Table 14: Public procurement

Instrument	Public procurement
Description	A policy instrument which provides financial support to CCUS technologies from the government, either through acquiring the generated carbon credits by governmental institutions or imposing such a requirement on suppliers of goods and services to public entities.
Successful application example	Sweden reverse auctions (early stages)
Timelines	Medium term: the development of the policy will require careful technical political and economic analysis which will require
Potential implementation agents	Government

Potential impact

Emissions:

Clear emission reduction pathway through CCUS solutions

Economic:

Economic pressure on the public budget and taxpayers

Swiss context

Switzerland

Main advantages

- Stable and predictable demand for CCUS carbon credits
 - Ability to establish technology-specific procurement volumes thereby regulating support provided to each technology and in each period
-

Main risks and challenges

- Economic pressure on the national economy
 - Lack of supply predictability
-

Source: the authors (2023)

Policy instrument review summary

The considered policy instruments have their advantages and disadvantages and may be suitable in the short or long term to support CCUS projects at different points of their journey to technology maturity. For this reason, it is important to develop a policy roadmap which will help to utilise these instruments if and when needed.

Some policy instruments will be important both in the short and long term and have the potential to support upscaling of CCUS projects, even though their exact design would depend on the sector's needs at the time. This category includes the de-risking instruments, coordination and development of transport and storage infrastructure and those instruments which can help create a stable and long-term demand for CCUS emission removals from the private sector (i.e. voluntary carbon markets (advance purchase agreements) and the modification of importers obligation).

Preparation for participation in compliance carbon markets, including both the readiness for EU ETS and international cooperation, also has strong potential but due to the time and effort necessary for such preparation, in the short term, their achievements will be limited but should take up once market

participation starts. That said, international cooperation in relation to CCUS projects is already gaining focus and has a growing potential in the near to medium term.

The policies which rely on public funding, such as direct funding and public procurement, would be suitable in the short term and could focus on helping CCUS technologies to mature. Later on, once the economic, regulatory and technological environment is suitable for private finance providers to take over, public funding could be phased out.

The informed combination and timing of implementation of these policies would help achieve the strongest results and provide adequate support to the CCUS sector supporting its maturing.

Strategy paper

Table 15: Summary of the considered policy approaches and their suitability in the short and long term

Policy instrument	Funder	Possible timeline	Overall potential	
			Short term	Long term
Incentivisation				
Carbon-price-floor inducing instruments	Public	Medium term	De-risking instruments will be crucial to help drive private investment to the CCUS projects and will be crucial both in the short and long term supporting the CCUS sector through various stages of maturity.	
Public-private coordination and cooperation on transport and storage infrastructures	Public/ private	Medium to long term		
Market generation				

Strategy paper

Advance purchase agreements in compliance or voluntary carbon markets	Private	Short, medium and long term	The advance purchase agreements are already emerging on the market and it is important to engage and support the shaping up of the market.	By their nature, they are long-term agreements and will be crucial for supporting long-term investor certainty.
Domestic offsetting for compliance with the compensation obligation	Private	Short term	Domestic offsetting is an already active tool and can support maturing of CCUS technologies.	As it relies on public funding, it may draw the funding away from other forms of climate projects which might have priority in the future.
Inclusion in ETS compliance	Private	Long term	CCS activities with geological storage are included in the EU ETS. The implementation of CCU activities with sequestration in long-lived products is currently discussed. Given the high cost of CCUS and a currently insufficient allowance price additional support may be required to kickstart this market short-term in Switzerland.	Inclusion of CCU in EU ETS together with an increase in CO ₂ allowance price and/or a combination of other incentives could, in the long term, help establish a strong financing stream from the private sector.

Strategy paper

Inclusion in International compliance carbon markets	Public/ private	Medium to long term	While CCUS projects just started getting in the focus of international cooperation, there are already examples under implementation and it will be important to continue their upscaling. In the short term, however, the emission reduction results may still be relatively limited.	Focus on international carbon markets on CCUS in the long term can help establish a strong financing stream from the private sector.

Regulation

Strategy paper

Sector agreements	Private	Medium term	Sector agreements can establish a clear sectoral pathway for development of CCUS projects. However, due to suitability of only certain sectors in implementing such projects and the limit of how much can be demanded of these enterprises, the progress may be steady but slow.	Sectoral agreements should capture the long-term perspective to give eligible companies more certainty. However, similar to the limitation of the short-term perspective, their ability to scale up these solutions will be limited.

Direct funding

Direct funding	Public	Short to medium term	Direct funding can be crucial to support maturing of CCUS technologies, however, due to the limited availability the emission reduction results may also be limited.	In the long term direct funding can become a burden on public finance. It is important to phase out the public support and create the necessary environment for private finance providers to take over.
Public procurement	Public	Medium term	Public procurement can be crucial to support maturing of CCUS technologies, however, limited funds can be constraining and inherently limit scalability.	In the long term public procurement can become a burden on public finance. It is important to phase out the public support and create the necessary environment for private finance providers to take over.

Source: the authors (2023)

Sectors and their strategies

Understanding sectoral specificities will play an important role in designing effective and efficient policy strategies. This section considers the main challenges associated with incentivisation of CCUS activities in specific sectors and what set of strategies and potential combinations of instruments could be applicable to them. The three sectors discussed in detail are those hosting the demonstration projects under DemoUpCarma which have been selected for their opportunities for near-term demonstration of CCUS value chains. In addition to informing the design of specific policy approaches in the targeted sectors, their analysis might help understand challenges and opportunities facing CCUS value chains in other sectors as well.

The sectors subject to the undertaken analysis are:

- **solid waste sector** – capture of CO₂ at solid waste incineration plants;
- **liquid waste sector** – sewage sludge treatment and CO₂ capture; and
- **cement sector** – CO₂-capture, biomass co-firing and, CO₂-mineralisation (storage).

Different strategies are proposed for each sector depending on whether the sector is already impacted by one of the instruments, such as those covered under the existing ETS, the sector agreement or the compensation obligation, or whether it is eligible for domestic compensation. The strategies contain elements that require action by industry actors (or their associations) as well as by federal and in some cases cantonal legislators, and in many cases both.

Solid waste incineration

Profile

The solid waste incineration sector in Switzerland is responsible for 4.2 MtCO₂, approximating to 4.5% of the country's greenhouse gas (GHG) emissions, of which 2.1 MtCO₂ are of fossil origin (FOEN, 2018). The solid waste sector is subject to an agreement with the federal government department Federal Department of Environment, Transport, Energy and Communications ((UVEK) for the reduction in emissions to be achieved at a sector level. Most mitigation has been achieved indirectly through utilisation of the heat in district heating, thus displacing other fuels and from the re-cycling of metals. In 2022, the agreement was extended and reoriented to reflect the overall federal objective of net zero and the associated need of achieving negative emissions. The new agreement includes the requirement for the construction and operation of at least one waste incineration plant with CCUS that achieves an annual capture rate of at least 100,000 tCO₂ by 2030, ramping up to 500,000 tCO₂ by 2035. This number includes carbon from both fossil and biogenic sources, which means that the resulting mitigation includes both a relative reduction in emissions as well as a removal of CO₂.

Compared to, for example, the cement sector, the solid waste sector is less exposed to competition. This is because of the typically long-term contract and status as quasi-public institutions. As a result, industry-wide coordination between solid waste plant operators is feasible, as the industry association's members are fairly homogeneous and the risk of sharing business secrets is limited. Hence, it is no surprise that the sector is arguably the most advanced, between the three sectors selected here, in terms of a coordinated CCUS approach, as demonstrated by the recent agreement signed between the Swiss Government and the sector's industry association VBSA.

Challenges

Compared to other point sources, solid waste incineration is faced with a couple of technical challenges, which are, however, surmountable. One of the main challenges is related to the purity of the waste incineration flue gas, whereby impurities, such as nitrogen oxides (NO_x) and sulphur dioxide (SO₂) can complicate the capture process and require additional purification methods.

Another challenge is scale: compared to cement plants, many waste incineration plants represent a smaller CO₂ point source often by an order of magnitude (ranging 30kT to 400kT in annual CO₂ emissions) and thus may struggle with higher relative costs associated with cleaning and capture modules, also building dedicated CO₂ transport infrastructure may more often be uneconomic – resulting in increased costs per tCO₂ captured and overall higher costs of CCUS.

Waste incineration facilities are often located close to or even in urban areas, which can create two distinct technical and socio-political challenges associated with the transport or use and storage of captured CO₂. Capture modules require substantial expansions of existing incineration plants and transportation infrastructure can add significantly to this. Direct rail access may be a requirement as the cost of truck transport rapidly becomes prohibitive.

From a political point of view, the sector agreement signed between the Swiss Government and the sector's industry association VBSA provides a good starting point, but the target for the single incineration plant and its mitigation volume is fixed for 2030. This could result in perverse incentives that cause construction of a compliance plant, where a long-term instrument could be more effective. This could lock in pilot plant scale activity potentially hindering scalability and further measures pre-2030 (Diego et al., 2017). Nonetheless, the first full-scale plant will be a crucial step and offer a key learning opportunity, which is expected to dramatically lower the threshold for subsequent plants. Nonetheless, it is important to examine how the industry can be properly incentivised beyond the single time-limited objective of building a compliance plant, intended to be operational in 2030. The risk is that the incentivisation is short lived and results in capture, transport and storage arrangements that may not lend themselves to long-term operation and scaling in connection with future infrastructure (Groenenberg, de Coninck, 2008).

The roadmaps that the waste sector is mandated to develop under the sector agreement offers an opportunity for producing Interim targets for the post-2030 period (as there are presently only additional targets in place for 2035 and 2050). While such dedicated long-term targets can provide

some planning certainty for investing in infrastructure necessary for scaling transport and storage, more refined 2030-2050 interim milestones set early on can allow a more rapid circle of planning, implementation and learning to ensure keeping with the necessarily rapid pace of scaling (Zapantis et al., 2019).

Strategy

A strategy that addresses the challenges of near-term CCUS implementation in the solid waste sector, but also paves the way for an industry-wide rollout in the future, is crucial to prevent a valley-of-death due to uncertainty or inadequate medium-term regulatory or financial incentives. For the long term, a vision for sustained operation of near-complete coverage of all Swiss waste incineration plants would appear appropriate to the Swiss net zero objective, given that the decarbonisation (and even achievement of negative emissions) is proving technically feasible and likely more accessible than in other sectors such as aviation and agriculture.

The regulatory approach may seem like the natural starting point, building on the existing sector agreement signed with VBSA. Recognising the present agreement's flaws, which were outlined in the previous section, and taking a somewhat more radical approach would be important. The main positive aspect of this approach is that it involves the relevant stakeholders and generally points in the right direction.

One central improvement of the sector agreement could be to move to negotiating more milestones, for example, in five-year increments that signal early on the need to move towards CCUS on all facilities in the medium term. Such signals would boost demand for CO₂ transport and storage services and thus allow early negotiation of necessary contracts, as well as launching the requisite permitting processes.

The implementation of regulatory levers can be key as, without external pressure, municipalities may choose to race to the bottom instead of undertaking decisive climate action. To avoid this, two additions to the sector agreement may be considered: first, an encompassing sector target that trends towards – or even beyond – net zero emissions and which guides the setting of intermittent milestone targets; and second, additional benefits and rewards targeting early movers and helping them overcome the hurdles involved in pursuing a still relatively novel measure – (e.g. reduced federal tax rates, capacity-building, or accelerated cantonal or federal permitting processes).

A revised sector agreement may also seek to differentiate between the emission reduction potential and the carbon removal potential of the solid waste incineration sector. According to Rosa et al. (2021), approximately 55% of Switzerland's domestic biogenic removal potential could come from incinerators, one of the highest potentials in all European countries.

Several additional push-and-pull levers may be used to nudge the sector towards CCUS development. For the former, consistent messaging and norm-building seems required in order to be able to internalise the additional cost of CCUS in the waste treatment fees over time. Pull measures include

Strategy paper

transport infrastructure readiness, which needs to be effective early enough for planning timelines to allow sequencing with more plants coming online before 2035.

Furthermore, the Bundesgesetz über die Ziele im Klimaschutz, die Innovation und die Stärkung der Energiesicherheit (KIG) offers the possibility of setting sector targets which could give further weight to any waste-sector, CCUS mandates. In ordinances flowing from the KIG, it will be important to ensure reference to emission reductions by a separate clear reference to carbon removals, as is already the case in the KIG, which offers important opportunities for specified targets and measures (Guarato, 2021).

The KIG passed the referendum in June 2023 which means that corresponding ordinances are to be developed, which might take some time. This is an opportunity to improve the regulatory landscape for CCUS scaling and for providing necessary financial support.

Market-generation measures could be pursued largely independently of regulation and can include: domestic offsetting; participation in advance purchase agreements; or other voluntary carbon markets. With the development of a crediting system for carbon removals in the EU, there is movement towards potentially enabling removal credits to be generated, which would allow crediting of the (biogenic) portion of waste incineration CCUS. Another pathway would be the inclusion of the waste sector under the ETS, which would incentivise use of CCUS.

Expanding the scope of the Swiss and EU ETS in one way or another allows for the integration of CCUS credits that would offer a long-term solution for sustainably incentivising CCUS in the waste sector. The EU Commission will assess in 2026 the possibility of including municipal waste incineration in the ETS, which would pave the way for including it from 2028 onwards. As Switzerland would likely have to follow suit, it may be advisable to examine the implications of such a change for the waste incineration sector and to draw up plans for increased use of CCUS for compliance.

Further incentivisation measures may be needed, however, to complement markets. To effectively address and bridge the price gaps in the short and medium term, additional federal policy instruments may be considered for providing greater investment certainty to support the communes that often are majority shareholder of WtE plants. This could be achieved, for example, by introducing dedicated incentivisation and de-risking instruments like CfDs, which could help secure public-private partnerships including with private investments to CCUS projects by providing sufficient and certain financial support over a long time period. Such structures would alleviate the burden especially for smaller communes or support those plants that are not publicly-owned.

As the waste incineration sector is already set to overcome the problem of piloting the first plant at scale, direct funding instruments could help with subsequent plants in this sector. To achieve a scalable transport infrastructure fit for transporting many hundreds of thousands of tons of CO₂ annually, public procurement of CO₂ transport services or guarantees of minimum transport volumes could help jump-start development of CO₂ transportation infrastructures by guaranteeing transport demand to a degree that might help overcome initial uncertainties that could prevent large-scale

Strategy paper

investments as needed e.g. for pipelines or terminals. The KIG article 7 provision of federal capital to address risks may be leveraged for this.

Summary

The following table provides a quick overview of the solid waste sector's relevance, state of play and challenges, as well as an indication of the strategies that could be employed.

Table 16: Overview of the solid waste incineration sector profile

Relevance for Switzerland	Responsible for 4.2 MtCO ₂ annual emissions, corresponding to ca. 4.5% of Switzerland's GHG emissions
Current state of play	Federally organised under VBSA
Challenges	• Additional purification methods for capturing CO₂ • Technical planning difficulties and socio-political criticism • Set volume for 2030 limiting incentive to go beyond • Clear post-2030 strategy missing • Disincentivisation through singular-limited objective
Strategy	• Define post-2030 strategy + targets • Work on a possibility to mobilise additional resources (e.g. via ETS) • Consistent messaging and norm-building • Examine options for lowering transport cost and advance transport infrastructure

Source: the authors (2023)

Liquid waste

Profile

There are approximately 800 sewage treatment plants in Switzerland. The sector's emissions stem from wastewater treatment processes that emitted 0.3 MtCO₂e in 2020 (up by 40% compared to 1990) with the total sector accounting for 0.7% of Switzerland's total GHG emissions. The liquid waste sector operators are organised under the industry association VSA (Verband Schweizer Abwasser- und Gewässerschutzfachleute), but unlike their counterparts in the solid waste sector, no sector agreement has been signed to date.

A couple of significant potentials for GHG mitigation in the liquid waste treatment sector can be identified, a prominent one being the capture of CO₂ during the cleaning of methane for introduction into the earth gas system. Several plants producing biogas today produce a pure CO₂ waste stream, which could easily be captured and transported for storage.

There is, furthermore, potential to increase biogas production from organic waste treatment (Bachmann et al., 2015; BFE, 2021) in particular from organic waste sources, such as food waste, fats and oils (Baker et al., 2019; Law et al., 2013).¹² Though emissions from landfills are in continuous decline as their operation stopped in 2000, they may nonetheless still offer some opportunities for methane capture.

Another mitigation potential for the wastewater treatment plants, using either the activated-sludge treatment or some form of (an-)aerobic or anoxic treatment processes, is an additional production and subsequent capture of nitrous oxide and methane emissions. Increasing the capture rate of these two GHGs can ultimately not only limit the global warming potential but also the ozone depletion potential of emitted GHGs (Tumendelger et al., 2019; Gruber et al., 2021).

Beyond these conventional options, the DemoUpCarma project demonstrates the feasibility of CCUS projects whereby sewage sludge can be anaerobically digested followed by mineral carbonation. Dried sludge combustion can also be combined with CCS – either in conventional underground storage sites or in a mineral carbonation process provided by the Carbfix and Neustark technology.¹³

¹² However, this only concerns a limited number of sites, as landfilling from municipal waste was banned in Switzerland in 2000.

¹³ Carbfix provides a permanent and safe storage solution for captured carbon, in which CO₂ is injected and rapidly turned into stone underground through proprietary technology that imitates and accelerates natural processes. Neustark provides a solution to remove CO₂ from the atmosphere by storing it in recycled concrete safely and permanently.

Challenges

Some of the previously identified challenges in the solid waste sector, but also their potential solutions, may in part also apply to the liquid waste sector, at least when it comes to the incineration of sewage sludge. For novel approaches such as the anaerobic digestion followed by mineral carbonation, the main challenge for now is demonstrating feasibility at pilot scale. The biggest challenge in sewage treatment is that the emissions from individual sewage treatment plants are dramatically lower than those of the waste incineration plants, which in return are relatively small emissions point sources when compared to cement plants. While a regulatory sector agreement approach could work to incentivise the first wastewater CCUS pilots, it is highly uncertain that scaled CCUS can work for the wastewater sector: the key challenge is the highly dispersed nature of emissions in this sector, which on average sees approximately 1 tonne of CO₂ per day and plant. Systematic adoption of CCUS across such a highly dispersed range of small-emission sources may not be achievable. Additionally, with no clear signal of push-and-pull incentives beyond 2030, the sector may get stuck in piloting mode rather than developing the foundations for scaling and sector-wide expansion.

Additional challenges are related to costs and incentivisation levels, since Switzerland's current domestic compensation price level seems insufficient for financing and eventually bringing down the high costs of capturing GHGs upon sewage sludge incineration and the high costs of mineralisation for storage. This is especially true for smaller wastewater treatment plants involving even greater costs associated with transportation of CO₂.

Strategy

In relation to the liquid waste sector, the regulatory approach could in principle mirror the one taken in the waste incineration sector (i.e. a sector agreement between VSA and the Swiss Government), though it may either take a technology-agnostic route (to incentivise scaling the locally most appropriate solution) or specifically target novel CCUS value chains. The same advantage applies to the waste incineration as well as the liquid waste treatment sector: operators do not have to fear competitive disadvantages as the clientele is completely captive and there is no competition, association members are fairly homogeneous and the risk of sharing business secrets is limited.

A dedicated strategy should include ambitious targets, up to 2030 and going beyond, with intermediate targets along the way. Furthermore, a continuous review and sharpening of the original targets and financial-support instruments should be included to raise ambition over time and avoid perverse incentives. In addition to that, potential cross-sector synergies and value chains should be further investigated. The obvious synergy is when those cement or waste incineration plants that cofire sludge are equipped with carbon capture capability. Presently biomass-cofiring in the cement sector amounts to 50 kt of sludge utilisation, though the total Swiss potential may be up to 200 kt (BFE, 2021).

Strategy paper

Apart from sector agreements, some additional instruments can be applied to provide financial support and limit investment risks for advancing local CCUS (resulting in carbonation in recycling concrete). These are as follows.

First, regulatory instruments, for example, designed as CCUS or removal obligations for certain sectors, would be the most stringent instrument. A CCUS or removal obligation also targeting the sewage sector could, for instance, be imposed on the fossil fuel importers, which are already mandated to compensate for their emissions. A revised mandate could, for example, obligate them to compensate for any emissions only with CCUS-based credits including from sewage CCUS. This idea has been recently discussed in academia and industry as the so-called 'carbon take-back' obligation. Another design feature of a regulatory policy could be that plant operators are commissioned by their municipalities to capture a certain amount of CO₂ by installing CCUS at their liquid waste treatment plants.

Second, complementing regulatory policies with direct funding instruments, like public procurement programmes, an ETS redistribution mechanism or even direct subsidies, can provide additional finance and also be designed in a fairly technology-specific way. As already demonstrated in the solid waste sector, the Swiss Government could set up a dedicated public procurement programme specifically for CCUS, which would clearly signal strong demand for these types of credits and could, in the long term, also bring down the costs of these technologies. Tapping into the ETS and redistributing some of the emission allowances' revenues into other vehicles is another direct funding opportunity. These vehicles can then use the resources received to provide direct funding to individual technologies or projects. Minding the size of the Swiss ETS, it would not be effective to support a broad basket of technologies, but it would make much more sense to only select a few technologies which are eligible for receiving funding.

Direct funding can also take the form of subsidies or tax breaks. These are especially relevant because they can be designed in a fairly technology-specific manner and provide finance for various stages in the research, development, deployment and diffusion (RDD&D) cycle. Hence, not only fully matured technologies can benefit from this instrument, but also those which are still in their technological infancy.

Third, with regards to market generation and incentivisation instruments, the liquid waste sector could also see inclusion into the ETS. In the long run, the existing Swiss ETS could be revised in a way that allows for the recognition of biogenic carbon CCUS – as is currently being considered at the EU level. The proposed inclusion of waste incineration in the EU ETS reform offers a way forward, at least for sludge incineration to become incentivised through the ETS. Eventually allowing companies and plants covered under the ETS to use such credits towards their obligations will likely result in increased demand for CCUS activities and the corresponding generation of removal-certificates. Given the currently high – but not high enough – ETS prices, this instrument will likely only become relevant in the long run, when prices are higher and costs for CCUS trend lower (not least thanks to the build out of a shared CO₂ transport- and storage infrastructure with public support).

Strategy paper

In parallel, Paris Agreement Article 6 market advances could also help lay the foundation for collaboration on storage of CO₂ abroad. To allow for the realisation of a full, cross-border CCUS project that includes all value-chain elements from the capture to the final storage, intensifying the collaboration with potential European storage providers and countries (e.g. Carbfix and the Icelandic government) will be important. Moreover, such a pan-European collaboration between state and non-state stakeholders can help limit investment risks by clarifying conditions and coordinating necessary steps for the transport and storage of CO₂.

Summary

The following table provides a quick overview of the liquid waste sector's relevance, state of play and challenges, as well as an indication of the strategies that could be employed.

Table 17: Summary of the liquid waste sector profile

Relevance for Switzerland	800 sewage treatment plants emitted around 0.3 MtCO₂e in 2020 The entire sector accounts for approx. 0.7% of Switzerland's GHG emissions
Current state of play	Federally organised under VSA
Challenges	• Clear targets for the short, medium to long term are needed, including interim targets until 2030 and post-2030 • Missing sector-wide agreement • Insufficient current carbon price levels to finance and bring down costs
Strategy	• Define pre- and post-2030 strategy as well as interim targets • Stress cross-sector synergies • Work on a possibility to mobilise additional resources (e.g. via ETS) • Strengthening readiness of international carbon markets • Intensity collaboration with (non-)state stakeholders interested in CCUS • Revising direct funding instruments to introduce, e.g. carbon removal obligations

Source: the authors (2023)

Cement plant CO₂ – capture, sludge co-firing and mineralisation

Profile

Although the cement sector has reduced its sector-wide CO₂ emissions by 35% since 1990, it still accounts for around 5% of Switzerland's total CO₂ emissions or roughly 2.9 MtCO₂ in 2019 (Cemsuisse, 2021). The concentration of these emissions is remarkable as Switzerland has only six operating cement plants (Swissinfo, 2021). The sector is subject to the Emissions Trading System (ETS).

In contrast to the solid and liquid waste sectors, cement is a highly competition-exposed sector with a less centralised industry association, Cemsuisse. Although the high degree of competition might not allow the same degree of cooperation as within the solid nor liquid waste sector, the cement sector has a strong potential to play a meaningful part in a circular economy. Cement production can achieve emissions reductions (conventional CCS), some removals (to the extent that biomass is co-fired), and recycling concrete can additionally also serve as a promising form of CO₂-storage.

Firstly, retrofitting the six existing cement plants and their largely fossil-based production processes with CCUS can significantly reduce CO₂ emissions. Cemsuisse has assessed the mitigation potential of a CCUS-equipped cement sector with around 70% by 2050 (compared to 2019 levels). However, Cemsuisse does not distinguish between the CCS and CCU potential, respectively, but prefers referring to the total CCUS potential instead.

Secondly, introducing biogenic fuels can – if captured and sequestered appropriately over a climate-relevant time period and accompanied by further efficiency gains – not only result in carbon-neutral cement but also in net-negative emissions.

Thirdly, this removal potential is even greater when considering using CO₂ as a resource in cement production, i.e. through the mineralisation process binding the CO₂ in the cement, as applied by Neustark. For all these reasons, focusing on the cement sector as part of the CCUS, as well as the wider mitigation strategy, underlines its significant potential.

Challenges

Unlike the solid waste sector, there is no sector agreement between the Swiss Government and the cement sector to build on as the sector is covered by the ETS. The cement industry is a highly competitive one which is less centrally organised. Given the coverage by the ETS it is somewhat incentivized to pursue CCUS – should (projected) allowances price level consistently exceed the cost of CCUS. A coordinated sector effort is currently largely missing as this has not been the case to date. Since early 2020, the Swiss cement companies have been participating in the Swiss ETS and are thus subject to a set emissions cap. This provides a limited, but arguably inadequate incentive for CCUS. Furthermore, the Swiss ETS does not currently cover emission reductions or removals achieved

Strategy paper

through storage in products. However, the current revision of the EU ETS includes a formulation allowing for durable storage in long-lived products where the CO₂ is chemically bound and not expected to enter the atmosphere under normal use, thereby integrating a broad set of CCU applications. According to the Message for Revision of the CO₂ Law (Botschaft zur Revision des CO₂-Gesetzes für die Zeit nach 2024) Switzerland is also supporting the EU's position to include durable storage in long-lived products in its latest revision (Schweizerischer Bundesrat, 2022). For the cement industry, such an adjustment would open the opportunity for serving as a CO₂-storage provider by utilising captured CO₂ in its production. It is, however, not clear whether this would provide sufficient incentive, at least for initial adoption.

Coordination e.g. joint ventures (potentially with some level of federal government backing) – among sector participants and with other CCUS actors – could reduce prices and thus render CCUS attractive under ETS incentives: Shared infrastructure investments would induce efficiency gains from economies of scale especially in regards to transport and storage. However, cement sector participants have to abide by competitive laws that preclude much of the further-advanced coordination due to risk of market-fixing. This is particularly challenging given the small number of actors and corresponding limited number of lessons learnt to be drawn from.

Utilising concrete production as a form of CO₂ storage is an option that would potentially also fit with regulatory provisions foreseen by the EU Commission's proposal for a carbon removal certification framework. The central question here is whether or how such certification could lead to demand by allowing for such credits to be traded towards the ETS caps, or separately as a market of its own. It would seem unlikely that production in Switzerland would be eligible for selling credits into the EU ETS.¹⁴

Strategy

As the costs associated with retrofitting cement plants with CCUS and the costs associated with the mineralisation process are still high, tailored policy support is needed to effectively bring down the costs. All identified archetypes of policy instruments (i.e. regulatory instruments, direct funding, incentivisation as well as market generation instruments alike) can provide this much-needed financial support.

A federal cement sector-specific overall target (as mandated by the KIG) could give more clarity on the intended use of CCUS in this sector and thus help generate momentum and interest in CCUS. It could be accompanied by a voluntary declaration of intent or a sector-wide strategy that outlines the regulatory and funding needs to achieve the first-of-its-kind CCUS plant in the cement industry. Such a step could perhaps be incentivized by proactive engagement at the federal level toward ensuring the orientation of investments and risk capital toward shared CO₂-management infrastructures necessary for it – as provided by Articles 6 and 7 of the KIG. Moreover, such a strategy could outline whether and

¹⁴ For further insights into how a revised ETS and accompanying policies could further support and accelerate the Swiss cement sector in a cost-effective way see Nakhle et al. (2022).

Strategy paper

what levels of additional funding may be needed (whether e.g. a carbon-contract-for-difference would be required, and if so at what level).

A separate regulatory approach towards incentivising CCUS in the cement sector is through public procurement conditions, whereby, for example, only carbon-storing cement types or cement produced with CCUS could be used for public construction contracts. Such a standard-based procurement regulation could be a powerful signal and enabler of a new suite of carbon-storing products and unlock long-term demand for such novel types of cement.

With regard to market generation instruments and the ETS, strategic revisions need to be implemented to fully incentivise the cement sector towards CCUS. The most immediate change for CCSU in the cement sector would be the adoption of rules allowing for the storage of CO₂ in cement to be counted under the ETS, in line with the current proposal for the EU ETS reform, which is to be mirrored in the Swiss ETS as per the federal council's communiqué regarding the CO₂ law.

However, given the likely insufficient or uncertain allowance price level and the high price sensitivity of cement as a product, de-risking instruments like CfDs could be particularly relevant in the cement industry. Mitigating the impact of price fluctuations seems key to mobilising the ETS' potential.

The voluntary carbon market will likely be a rather niche opportunity for the cement industry given the size of individual plants. Nonetheless, with more and more funds for advance market purchase agreements emerging, pilot plants could potentially also benefit from such funding – at least for an initial operating period.

Summary

The following table provides a quick overview of the cement sector’s relevance, state of play and challenges, as well as an indication of the strategies that could be employed.

Table 18: Summary of the cement sector profile

Relevance for Switzerland	The six cement plants account for approx. 5% of Switzerland’s GHG emissions
Current state of play	Nationally organised under Cemsuisse
Challenges	• No sector agreement in place • Clear medium- and long-term strategy missing • More competition between sector stakeholders • ETS revision needed
Strategy	• Sector agreement can help lay the foundation for CCUS rollout • De-risking instruments mitigating the impact of price fluctuations • Define clear and ambitious decarbonisation and removal pathway for cement sector

Source: the authors (2023)

Strategies regarding underground storage and transport

Following the sectoral analysis for the Swiss solid waste, liquid waste and cement sector, it is also important to consider the last element of the CCS value chain – the storage and sequestration part¹⁵, which is a cross-cutting issue relevant for all sectors analysed. A handful of challenges can be identified with regard to the geological storage situation in Switzerland.

First, although it is well understood that appropriate geological formations need to be available and operational, which is also mandated by the federal law on climate protection goals, innovation and strengthening energy security (Bundesgesetz über die Ziele im Klimaschutz, die Innovation und die Stärkung der Energiesicherheit [KIG])¹⁶, the actual domestic storage potential in Switzerland is uncertain and widely regarded as hard to tap into, given population density and the high cost of infrastructure in Switzerland. This can be seen in the last mapping exercise of potential storage sites in Switzerland which is already over 10 years old. Hence, an update of that mapping (based on the latest scientific finding and using new monitoring and risk assessment tools) is long overdue and the program pursued in response to Parliamentary Request N° 20.4063 which includes the operational steps needed to identify promising storage sites in Switzerland (integrating relevant geological as well as socio-economic factors) could be considered.

Second, societal issues and fairness considerations need to be addressed in due time. Despite mitigation deterrence and moral hazard arguments that are part of nearly every removal discussion, societal criticism is also especially directed to the storage part. Hence, any potential CCUS policy should include a holistic assessment of any issues and concerns that are raised by society. Fears and concerns regarding the processes or the safety of the stored carbon, which are inherently linked to similar debates on nuclear waste disposal, need to be fully addressed.

The hesitance toward domestic underground storage may also increasingly be criticised in international debates about fairness and justice. In those discussions, Switzerland is seen as a historic emitter, who should take full responsibility for its historic emissions and not encumber other countries with providing solutions for necessary climate action. Yet accessing international storage may also be justified as the most rapidly available form of storage – as other countries in Europe have access to storage in depleted oil and gas reservoirs and saline aquifers including offshore, which is proving a significant advantage to prevent public backlash and transportation-related risks to populations.

Although political-technical and societal aspects point to two different challenges when it comes to international storage, strategies to overcome them might overlap as they pertain to i) the complexity of the CCUS value chains, ii) multiple modes of transport and ii) multiple interacting storage sites

¹⁵ This section only focuses on the geological storage of CO₂ and not on any short- or long-lasting utilisation methods or products.

¹⁶ The KIG states that the confederation and cantons are responsible to ensure that adequate storage sites are available in Switzerland or abroad by 2050 (KIG, Art 3.5).

requiring a coordinated and compatible approach on a technological and institutional level. Within the European context, this will also involve cross-border transport infrastructure and hubs and clusters that might need to use shared infrastructure to be economically viable and reduce and share liabilities alike. Hence, Switzerland should expand its relationship with European countries to share experiences and link Swiss CCUS projects to a wider European infrastructure. Tackling this early on will help secure access to adequate transport and storage capacity. Though it may be noteworthy that some political barriers to cooperation with the EU may also raise the cost of CO₂ handling for Swiss entities that pave the way to requisite infrastructure projects (as, for example, not many Swiss entities are participating in research and development cooperations, e.g. Projects of Common Interest (PCI)). Continued participation of Swiss entities in EU projects from early scoping to planning of implementation (as sometimes funded through, for example, Horizon projects) is an important component for ensuring adequate representation of Swiss interests regarding CO₂ transportation and storage infrastructures.

Moreover, consideration should be given to incorporating into the regulation implementing the new climate law a specification for the provision in Article 3, which highlights that “the Confederation and the cantons ensure that by 2050 at the latest in Switzerland and abroad carbon stores are available in the necessary volume...” This, we anticipate, will in practice require that dedicated agreements are negotiated with public and private actors in neighbouring countries for the economic transport and storage (at appropriate volumes) of CO₂ from Switzerland. Switzerland needs to be linked to the European CO₂ infrastructure development right from the start, as demand from actors requiring access to such infrastructures will increase over time and the proper supply and installation of infrastructure might be a lengthy process. Dedicated agreements and contracts should not only address supply and demand for infrastructure needs and direct corresponding financial payment flows but also provide a legally sound basis for determining risk and liability of CCUS projects, such that both Swiss and European regulation is sufficiently compatible on these crucial elements. Such agreements should, for example, also provide a clear understanding of which entity is responsible and liable (until when) if leakages along the CCUS value chain occur and also which entity would be the rightful owner of the CCUS mitigation results. Furthermore, such agreements seeking to ensure storage availability need to align with current provisions of the EU ETS and the Swiss ETS that are already applicable to some of the entities that will participate by capturing CO₂ and seeking to have it transported abroad for storage.

Conclusion

Mobilising funding for CCUS value chains through their initial phases towards scaling is challenging. While there are strategies which could lead to incentivising development and deployment of CCUS technologies they may not work in isolation as challenges to piloting and later upscaling can be rather unique for each stage and technology. Strategies should thus be carefully tailored using the array of available policy instruments, targeting them for the needs of each sector. Moreover, they should be aligned with the country-wide technology priorities so it would be beneficial to develop a technology prioritisation and targeted, emission-reduction split on the national level to inform relevant policy decisions.

The policy instruments examined in this report focus on incentivisation, market generation, regulation or direct funding. With regards to the selection of the policy instruments, it will be important to apply the right instruments at the right time in order to help CCUS technologies mature, maximise the benefit of public funding and create conditions and policy frameworks for mobilising the growing flow of private resources to the CCUS projects.

- **Short and long term:** some policy instruments will be important both in the short and long term, such as de-risking instruments, coordination and development of transport and storage infrastructure, as well as those instruments which can help create a stable and long-term demand for CCUS emission removals from the private sector (i.e. voluntary carbon markets, advance purchase agreements and the modification of importers obligation).
- **Short term:** policies relying on public funding would be one of the most direct and straightforward instruments in the short term and can help CCUS technologies mature. However, their long-term use could be phased out with the expectation that the private sources of finance, such as voluntary and compliance carbon markets, will replace their funding.
- **Long term:** developing readiness for participation in compliance markets, which have high potential in the medium to long term requires early preparation. That said, international cooperation in relation to CCUS projects is already gaining attention in the EU and has a growing potential in the near to medium term if Switzerland mirrors some of these developments that hold long-term promises.

The informed combination and timing of implementation of these policies in a sector-specific manner would help achieve the strongest results and provide adequate support to the CCUS sector, helping it mature. The following considerations relate to the three high-potential sectors analysed in this study.

- **Solid waste incineration:** given the existence of the sectoral agreement requiring the installation of one CCUS value-chain, long-term incentives and mechanisms rewarding overachievement of the set targets would be crucial. Additionally, including sectoral emission reductions in the compliance markets and creating a stronger policy framework via changes

Strategy paper

to the Swiss CO₂ Act would be beneficial.

- **Liquid waste:** introduction of a sectoral agreement similar to the one of the solid waste incineration sector could be an effective first step in promoting introduction of CCUS technologies in this sector, yet it would require incorporation of certain sector-specific amendments. Due to the higher cost of CCUS in the liquid waste sector, direct funding, public procurement and other instruments relying on public financial support may be combined to also ensure smaller entities could pursue CCUS financially. The importance of voluntary and compliance markets for this sector is also high. However, to effectively engage with them, the cost of accessing CO₂ transportation and storage infrastructures will need to be reduced.
- **Cement plant CO₂-capture, sludge cofiring and mineralisation:** this sector deserves special attention for the implementation of CCUS technologies due to its potential of offering decentralized small-volume storage opportunities in long-lived products. The cement sector faces higher level of competition in comparison to the solid and liquid waste treatment facilities and may thus require specific policies increasing demand for low-carbon cement. They would include public procurement for low-carbon cement and allow recognizing carbon storage in products under the ETS.

The matrix demonstrating applicability of the considered policy approaches to the selected sectors is presented in Table 19 (below).

Table 19: Sector-specific considerations for application of policy instruments

Incentivisation	Solid waste	Liquid waste	Cement
De-risking instruments		Relevant for all sectors	
Coordination for the development of transportation and storage infrastructures		Relevant for all sectors	
Market generation			
Voluntary carbon markets: advance purchase agreements	Relevant for all sectors		

Strategy paper

Incentivisation	Solid waste	Liquid waste	Cement
Domestic offsetting	Relevant for all sectors		
Readiness for ETS compliance	Inclusion of sectoral emission removals in ETS should be considered.	Inclusion of sectoral emission removals in ETS should be considered.	Inclusion of storage in long-lived products should be considered.
Readiness for international carbon markets	Relevant for all sectors		
Regulation			
Sector agreements	Extending the agreement and a mechanism to reward additional ambition, would be an alternative to future ETS inclusion.	Lessons learnt from the solid waste sector.	Could not formally duplicate ETS obligations (voluntary commitment for first CCUS installations).
Direct funding			
Public procurement	Public procurement on the sectoral level is less relevant.	Public procurement is relevant given the higher costs of technologies in this sector.	Public procurement can include not only carbon credits but also low-carbon cement.
Direct funding	Direct funding on the sectoral level is less relevant.	Direct funding is relevant given the higher costs of technologies in this sector.	Direct funding is relevant given the higher competition faced by the sector.

Source: the authors (2023)

Strategy paper

Additionally to sector-specific policies, creating the necessary incentivisation conditions through the development of the necessary transport and storage infrastructure would be crucial for the overall development of CCUS technologies and should therefore be a priority.

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CCS+ Initiative - introduction to methodological work

DemoUpCARMA

Work Package 5: addressing policy, regulatory and acceptance challenges to enable CCUS deployment

Task 1: emissions accounting, reporting tools and climate finance mechanisms of negative emissions for national and transnational CCUS solutions

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Table of contents

1. Carbon crediting infrastructure	4
2. Applicability of CCS+ methodologies for DemoUp	7
3. Bibliography	10

List of tables

Table 1: Overview of methodological outputs and guidance notes in latest workplan	5

List of figures

Figure 1: Interplay of relevant methodological plug-and-play setup for DemoUp value chains	8

1. Carbon crediting infrastructure

Since its foundation in 2021, the CCS+ Initiative has brought together over 50 stakeholders to develop a comprehensive carbon accounting infrastructure under Verra's Verified Carbon Standard (VCS) Program for technologies that capture, transport, utilise and store carbon dioxide (CCS and CCUS), including engineered carbon dioxide removal (CDR) technologies. The robust and environmental sound methodological development is at the core of the initiative's mission to scale and unlock carbon finance for projects that reduce or remove carbon emissions, which are currently not financially viable, yet sorely needed to reach international climate goals.

Existing practices in carbon crediting methodologies cannot appropriately cater to a complex, integrated and often even cross-border carbon management model as they narrowly address a specific project value chain, rather than the complete industrial cluster. The reality is that the rules, requirements, criteria and procedures to generate credible emission reduction or removal carbon credits from high quality carbon management projects have not been consistently available or have been limited to certain geographies or project types. Those methodological approaches currently available for CCS and CCUS are limited in numerous ways: some lack clear and consistent definitions of project eligibility and project boundary, others have unclear or weak guidance on the implementation of additionality testing, or are limited to specific jurisdictions.

Against this background, the CCS+ Initiative has developed a comprehensive and integrated carbon crediting infrastructure that offers a platform for a wide array of project types (see for an overview of methodological approaches the table below). Its entire infrastructure is designed in an innovative plug-and-play modular fashion, which means that individual activities in the CCS and CCUS value chain are represented by respective methodological modules that can be seamlessly combined with the relevant modules of other activities. Under the latest VCS rules and their requirements for geological carbon storage projects, a CCS and CCUS project is required to include all three value-chain elements from the capture, to the transport and ultimately the storage or utilisation of CO₂, i.e. only a project representing an entire CO₂ value chain is eligible.

The CCS+ methodological architecture is composed of two framework methodologies (CCS methodology and CCUS methodology), which establish overarching parameter and procedures to quantify greenhouse gas (GHG) emission reductions and removals from CCS and CCUS projects. They also define eligibility criteria and provide overarching requirements for such projects. These framework methodologies are further underpinned by modules covering individual capture, transport, long-term utilisation or geological storage processes, leading either to emissions reductions or removals. A set of additional tools is developed to support the proper functioning, such as a tool to distinguish in a single project between emissions calculated for the purpose of monetisation in the voluntary market and those covered under a given compliance market (VCS vs. non-VCS). Another tool is used to differentiate between the origin of the emissions in projects involving both fossil and biogenic emissions, such as waste-to-energy plants.

In addition to the development of the methodologies, modules and tools, the Initiative is developing so-called compliance notes. The aim of these notes is to assess the adoption of an integral carbon accounting infrastructure for various regulatory regimes and (compliance and voluntary) market systems (see for an overview of compliance notes also the table below). The notes take stock of the current landscape and status quo, explore opportunities and challenges for adoption, and identify synergies with existing regulations and policies.

Table 1: Overview of methodological outputs and guidance notes in latest workplan

Methodological document	Status
Methodology for Carbon Capture and Storage (CCS)	Public consultation completed
Methodology for Carbon Capture and Utilisation and Storage (CCUS)	Concept Note
Methodology for short-term utilisation of Carbon (CCU)	Under discussion
Methodology for Carbon Dioxide Removal (CDR)	Under discussion
CO ₂ Capture from Air (Direct Air Capture)	Public consultation completed
CO ₂ Capture from Biogenic Sources (BECCS)	Pre-public consultation, PC expected for Q4/2023
CO ₂ Capture from Power and Heat	Pre-public consultation, PC expected for H1/2024
CO ₂ Capture from Industrial Processes	Pre-public consultation, PC expected for H1/2024
CO ₂ Capture from Oil and Gas	Pre-public consultation, PC expected for H1/2024
CO ₂ Capture from Pre-combustion/Oxyfuel	Pre-public consultation, PC expected for H1/2024
Consolidated Module for CO ₂ Transport	Public consultation completed
CO ₂ Storage in Saline Aquifers	Public consultation completed
CO ₂ Storage in Depleted Oil and Gas Reservoirs	Pre-public consultation, PC expected for Q4/2023
Mineralisation of CO ₂ in igneous rock formations	Concept Note
Utilisation of CO ₂ in concrete	Concept Note
Utilisation of CO ₂ in aggregates	Concept Note
Utilisation of CO ₂ in short lifetime products (fuels)	Under discussion
Utilisation of CO ₂ in short lifetime products (plastics)	Under discussion
Tool for Differentiation between Emission Reductions and Removals in Carbon Capture and Storage Projects	Pre-public consultation, PC expected for Q4/2023

Methodological document	Status
Tool for Baseline Quantification and Allocation of Project Emissions in Projects with VCS and non-VCS-CO ₂ flows in Carbon Capture and Storage Projects	Pre-public consultation, PC expected for Q4/2023

Guidance Note	Status
EU Guidance Note	Published
Article 6 Guidance Note	To be published in Q4/2023
US Guidance Note	In progress
Three domestic use cases: Switzerland & Sweden & Kenya	Under discussion
Using CCS+ outputs to create a race-to-the-top across all carbon crediting programmes in the VCM	Under discussion
Gulf Region Guidance Note	Under discussion
Cross-border use cases: Norway-Denmark & Japan-SEA & Switzerland-Iceland	Under discussion

(Source: Authors, 2023)

Note: The methodological documents included in the table above and marked “Public consultation completed” were submitted already for public consultation in July 2023. Hence, they are publicly available on Verra’s website (Verra, 2023).

The methodological documents included in the table above and marked “Pre-public consultation” are currently being prepared for its public consultation in Q4/2023 and H1/2024 respectively, hence are not publicly available and cannot be published yet.

The methodological documents included in the table above and marked “Concept Note” are in an earlier conceptual stage and are not publicly available, hence cannot be published yet.

The methodological documents included in the table above and marked “Under discussion” will be developed if CCS+ members approve their scope.

The same logic applies to the status of the Guidance Notes included in the table above. The EU guidance note is publicly available on the CCS+ website, the soon to be finalised Article 6 Note will also be published there (CCS+, Initiative 2023).

2. Applicability of CCS+ methodologies for DemoUp

For the DemoUp value chains, which monetisation options are further discussed in the respective Blueprints in D.5.3, the following set of outputs developed by the CCS+ Initiative can be used.

I) For a biogas upgrading facility with subsequent utilisation of the captured CO₂ in concrete the following documents are relevant:

- Methodology for Carbon Capture and Utilisation and Storage (CCUS),
- Module for CO₂ Capture from Biogenic Sources,
- Consolidated Module for CO₂ Transport,
- Utilisation of CO₂ in concrete,
- Tool for Baseline Quantification and Allocation of Project Emissions in Projects with VCS and non-VCS-CO₂ flows in Carbon Capture and Storage Projects (if the CO₂ captured in the biogas facility is mixed with CO₂ from other sources before being utilised in concrete).

II) For a waste-to-energy plant with subsurface supercritical CO₂ storage in saline aquifers the following documents are relevant:

- Methodology for Carbon Capture and Storage (CCS),
- Module for CO₂ Capture from Biogenic Sources,
- Consolidated Module for CO₂ Transport,
- CO₂ Storage in Saline Aquifers,
- Tool for Differentiation between Emission Reductions and Removals in Carbon Capture and Storage Projects¹,
- Tool for Baseline Quantification and Allocation of Project Emissions in Projects with VCS and non-VCS-CO₂ flows in Carbon Capture and Storage Projects (if the CO₂ captured in the waste-to-energy plant is mixed with CO₂ from other sources before being stored in saline aquifers).

III) For a cement plant with subsequent storage via subsurface mineralisation the following documents are relevant:

- Methodology for Carbon Capture and Storage (CCS),
- Module for CO₂ Capture from Industrial Processes,
- Consolidated Module for CO₂ Transport,
- Mineralisation in igneous rock formations,

¹ The combination of the *Module for CO₂ Capture from Biogenic Sources* and the *Tool for Differentiation between Emission Reductions and Removals* covers both the fossil and biogenic CO₂.

- Tool for Differentiation between Emission Reductions and Removals in Carbon Capture and Storage Projects²,
- Tool for Baseline Quantification and Allocation of Project Emissions in Projects with VCS and non-VCS-CO₂ flows in Carbon Capture and Storage Projects (if the CO₂ captured in the cement plant is mixed with CO₂ from other sources before mineralisation).

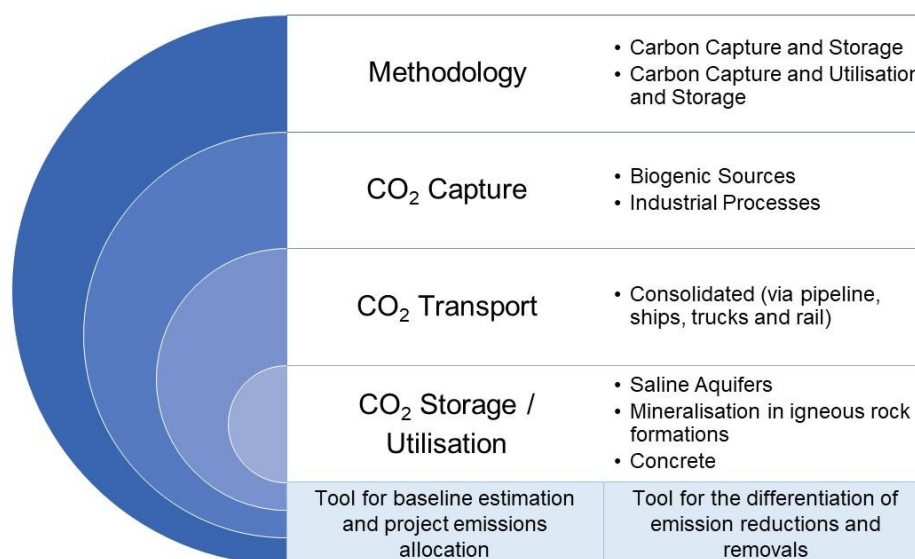


Figure 1: Interplay of relevant methodological plug-and-play setup for DemoUp value chains

(Source: Authors, 2023)

As can be seen in the overview table, the CCS+ Initiative is also going to develop a dedicated module for the CO₂ mineralisation in igneous rock formations, i.e. in basaltic rock and peridotite formations. The work on the development of this mineralisation module is scheduled to start in the Q4/2023 and will include the pioneering organisations in the field of mineralisation, Carbfix, 44.01 and Cella, all members of the CCS+ Initiative.

In absence of an available mineralisation methodology developed by the CCS+ Initiative, the methodology jointly developed by the CCS+ members Climeworks and Carbfix in the meantime is referenced here (Carbfix, 2022). In accordance with ISO 14064-2:2019, the developed methodology defines applicability conditions and procedures to quantify project emissions and greenhouse gas

² The combination of the *Module for CO₂ Capture from Industrial Processes* and the *Tool for Differentiation between Emission Reductions and Removals* covers both, the fossil and biogenic CO₂ potentially used for cofiring.

(GHG) emissions mitigations for projects using mineral storage. It also outlines a monitoring approach, which parameters and data are to be considered and monitored over a given time period. Furthermore, and closely aligned with the CCS Directive, it provides guidance on post closure and liability transfer to the state or competent authorities.

It must be stressed however, that this methodology has been developed in isolation and is not accepted by a specific (voluntary or compliance) carbon market standard-setting organisation as of yet.

3. Bibliography

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Blueprint 1:

Domestic CCUS value chain -

Biogas upgrading capture

with utilisation in concrete

DemoUpCARMA

Work Package 5: addressing policy, regulatory and acceptance challenges to enable CCUS deployment

Task 1: emissions accounting, reporting tools and climate finance mechanisms of negative emissions for national and transnational CCUS solutions

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Table of contents

1. Summary	5
2. Background and Objectives	8
2.1 Challenges for monetisation of CCUS activities	8
2.2 Blueprint Focus	9
2.3 Objective	10
2.4 Materials and methods	11
3. Description of the value-chain use case	12
3.1 Description of the Scope of Activities	12
3.2 Technical feasibility and barriers	13
4. How to generate and monetise credits under the VCM	14
4.1 CCUS methodology beyond CCS+ Initiative	18
4.2 Use of VCM credits or dedicated crediting for use under Article 6.2	20
5. Swiss compensation scheme	21
5.1 Procedure towards carbon credits	22
5.2 Eligibility of the proposed CCUS project value chain	23
6. Swiss emissions trading system	27
7 EU Carbon Removal Certification Framework	28
8. Potential (future) crediting and monetisation options	29
8.1 Article 6.4 – centralised Mechanism	29
8.2 ICAO – an emerging source of demand for credits	29
9. Barriers and opportunities for action	30
10. Bibliography	31

List of tables

Table 1: Project boundary	12

List of figures

Figure 1: Process for developing a biogas upgrade-CO2-capture – international transport – storage value-chain as a (voluntary) carbon market project for generating and selling credits.	6
Figure 2: The value-chain and monetisation option detailed in this blueprint.	10
Figure 3: Overview of the four possible avenues of monetising mitigation results examined in the four blueprints	11
Figure 4: Criteria relevant to the integrity of carbon credits – to be demonstrated transparently by the standard	14
Figure 5: CCUS Methodology, its modules for capture, transport and utilisation and accompanying tool applicable in this blueprint	15
Figure 6: The carbon project cycle from idea to issuance of credits	16
Figure 7: The core elements of a project design document (PDD)	16
Figure 8: Swiss compensation scheme procedure	22

1. Summary

This blueprint explains how to generate carbon credits from a biogas upgrade plant with carbon dioxide (CO₂) capture, utilisation and storage. It considers a domestic value chain with CO₂ capture at a biogas upgrade plant and CO₂ storage in concrete, both located in Switzerland. It is part of a suite of four blueprints produced under the DemoUpCarma project to aid the monetisation and scaling of carbon capture, utilisation and storage (CCUS)¹ in Switzerland under voluntary and compliance markets, both domestic and international. The blueprints collectively assess the following market cases:

- certificate sales via the voluntary carbon market (VCM)
- domestic compensation instrument under the Swiss compliance market
- international transfer of mitigation outcomes achieved abroad
- emission trading systems (ETs)

and the following carbon capture, utilisation and storage (CCUS) applications:

- CO₂ capture from a biogas upgrade plant, a WtE plant, and a cement plant
- CO₂ transportation via trucks, rail, ships and barges
- CO₂ storage in concrete, subsurface supercritical CO₂ storage, and subsurface mineralisation

To help project developers in their quest to monetise – and thereby enable – CCUS adoption, each blueprint presents:

- an overview of challenges for the monetisation of CCUS activities
- monetisation options for CCUS in voluntary and compliance markets
- step-by-step guidance to generate credits
- considerations for the monetisation of credits
- barriers and opportunities for action

This particular blueprint explains the specific steps needed, the implications of various crediting systems, and opportunities for immediate action toward crediting and monetising mitigation results from a CCUS value chain consisting of:

- CO₂ capture from a biogas upgrade plant
- CO₂ transportation via trucks
- CO₂ storage in concrete

It guides through the process to monetise such a CCUS activity (Figure 1), from establishing a partnership along this Swiss CCUS value chain to selling and sharing the revenue from the carbon credits generated.

¹ This report, exclusively uses the term carbon capture, utilisation and storage (CCUS) to cover any type of activities ranging from carbon capture and storage in geological formations to carbon capture, utilisation and storage in durable products resulting in long-term storage.

Blueprint 1 – Domestic CCUS value chain



Figure 1: Process for developing a biogas upgrade-CO₂-capture – international transport – storage value-chain as a (voluntary) carbon market project for generating and selling credits.

Carbon credits could provide a revenue stream to cover the additional cost of CCUS beyond the biogas upgrading-related cost. Generating the carbon credits, however, is not straightforward. It involves a somewhat complex procedure to ensure a high-quality standard and environmental integrity in the quantification and certification of emission reductions or removals through CCUS activities.

Used as a companion to formal documents setting out requirements and processes under the Swiss domestic compensation system, this blueprint helps anticipate the main challenges for monetising CCUS from a Swiss biogas upgrading, and domestic CO₂ transport and CO₂ storage through mineralisation in concrete. It contains a step-by-step guide to submitting a project under the Swiss domestic compensation system and demonstrating compliance with its requirements. Key challenges even before submitting a project are explained, such as defining which entity (among many involved along the value-chain) will be the project proponent to whom credits will accrue and how to arrange for the appropriate sharing of carbon credit revenues among value-chain partners. With an example, the blueprint illustrates how to describe the project scope, i.e., how to determine the project boundaries in time and space, and the suitability of the activity with carbon accounting methodologies. This document discusses the considerations and requirements for project development within the voluntary carbon market (VCM). These aspects are systematically addressed in a designated Project Design Document (PDD). Under the framework of the Swiss compensation scheme, a corresponding document encompasses similar key topics such as the activity outline, baseline, and monitoring methodology. Complying with these requirements is crucial for meeting the Swiss compensation or VCM criteria and, more importantly, to ensuring a high-quality standard and high environmental integrity of the mitigation credits.

The blueprint, furthermore, provides guidance to navigate the evolving and increasingly complex carbon markets. Including key considerations for generating high-quality carbon credits under the Swiss domestic compensation system and with a brief comparison of requirements compared to voluntary carbon markets and other compliance markets. For this, the blueprint points to possible developments regarding compliance markets, notably the implications for cases where biogas upgrading actors become included in the ETS (e.g. should the liquid waste sector eventually also be included in the ETS) and should the ETS be reformed to also recognise capture and storage from sustainable biomass sources. Furthermore, it addresses the possibility of generating credits under Paris Agreement Article 6.2 and Article 6.4.

Key considerations on monetisation across market systems are: The Swiss domestic compensation system is expected to offer stable prices compared to international voluntary, due to the non-delivery fee. Should the sector in which biogas upgrading with CCUS is pursued become subject to the Swiss ETS and should biogenic sources be recognised in the ETS, no domestic credits could be generated any more. However, although the inclusion of removals in the ETS is currently very

Blueprint 1 – Domestic CCUS value chain

unclear, in the case of CCUS from biogas upgrading, the project should benefit from generating revenue by being able to sell surplus allowances.

2. Background and Objectives

Developing a CCUS industry is challenging: multiple interlinked sectors and actors need to cooperate based on the shared interest in generating revenue related to climate change mitigation results. This requires creating an ecosystem of compatible interfacing logistical, technological and contractual pieces working cooperatively across a significant number of private sector actors and in compliance with carbon market rules, while also ensuring compliance with national accounting in multiple countries. Despite advancements in pilot value chains funded by subsidies or induced by regulatory obligations, transitioning to a scalable business model reliant on carbon revenue or incentives from emissions trading remains challenging.

The potential of storing in long-lived products – as exemplified by this blueprint’s case of storage in concrete – is particularly relevant to managing smaller point sources and it offers economic advantages due to shorter transport distances. Additionally, such storage in products may sidestep concerns related to storage services provided by powerful oil and gas companies that might be seen to overpower the much smaller and novel carbon capture solution providers. Currently, there are limited robust standards for tracking mitigation results as required for scaling CCUS despite relying on such results toward medium to long-term mitigation goals: While initial CCUS pilot projects can be implemented based on regulatory obligations and innovation-supporting funds, scalable long-term funding for CCUS with clear climate benefits remains elusive. Effective climate action thus demands leveraging voluntary carbon markets to swiftly unlock revenue and draw lessons learned for regulatory approaches, many of which appear set to adopt key structures and methodologies from the first-mover VCM.

2.1 Challenges for monetisation of CCUS activities

This blueprint addresses two challenges:

- 1) the lack of robust methodologies for tracking mitigation results from CCUS, and
- 2) the lack of clarity on accounting, responsibilities and ownership in carbon market projects within the complexity of CCUS hubs and clusters.

Need for a cohesive ensemble of carbon-tracking methodologies

The absence of a unified carbon accounting methodology has hindered CCUS projects from accessing carbon markets effectively. Traditional methodologies have been narrow, focusing on specific project chains rather than the comprehensive industrial ecosystem needed for effective carbon management. This fragmentation has hampered the generation of reliable credits from CCUS projects, especially those in larger interconnected systems. However, recent efforts, led by the CCS+ industry consortium in collaboration with Verra (associated with the Verified Carbon Standard (VCS)), aim to develop a comprehensive suite of methodology modules to address this gap.

The CCS+ Initiative introduces an advanced carbon accounting system for varied CCUS projects, using a modular approach for activities across capture, utilisation and storage. Its ‘plug-and-play’ system recognises shared infrastructures across CCUS technologies, enhancing adaptability to fit the numerous possible combinations across multiple hubs and clusters (CCS+ Initiative, 2023). The carbon accounting landscape had long been fragmented and lacked consistency across the emerging CCUS ecosystem. Though Verra and the Gold Standard have made progress, these standards would benefit from more stringent overall oversight to ensure long-term credibility via a

Blueprint 1 – Domestic CCUS value chain

coherent carbon accounting framework that also conforms with evolving formal accounting rules under the Paris Agreement. High-quality, evolving methodologies can ensure transparency. Adopting stringent, up-to-date standards can streamline quality assurance, reducing costs and increasing efficiency throughout CCUS value chains. While this blueprint primarily emphasizes the carbon accounting landscape within the VCS, Section 4.1 offers an outlook of additional CCUS methodologies that assist early movers in securing revenue within the VCM.

Need for disambiguation of accounting, responsibilities, and ownership

CCUS activities can achieve two different types of results, which need to be clearly differentiated depending on the source of carbon: reductions in emissions in the case of fossil carbon and removals of CO₂ in the case of biogenic carbon, which need to be transparently tracked and communicated. A domestic-only activity as examined here may avoid some additional challenges that projects involving the transport of CO₂ transport across nations face. Other ambiguities concerning ownership, liability, and carbon-revenue accrual, however, also pertain to novel CCUS value-chains and require clarification through appropriate contracts among value-chain partners based on considerations of technical and institutional nature such as ensuring that project owners have control over the durability of storage. Lacking clarity regarding project ownership, liability or contractual assurance can become problematic in case of leakage or when regulations and carbon market rules evolve. In the case of storage in inherently chemically stable products, however, such concerns will be limited to CO₂ capture, processing, and transport (i.e. the steps preceding final storage). Creating clear contractual arrangements among partners is vital and should draw from best practices and existing guidelines to maximise compatibility when multiple sources are processed and stored via the same plants.

2.2 Blueprint Focus

The focus of this blueprint is generating carbon credits from a Swiss biogas upgrading capture facility, with transport via trucks and storage in concrete under the Swiss compensation scheme (Figure 2). Section 3 provides further details.

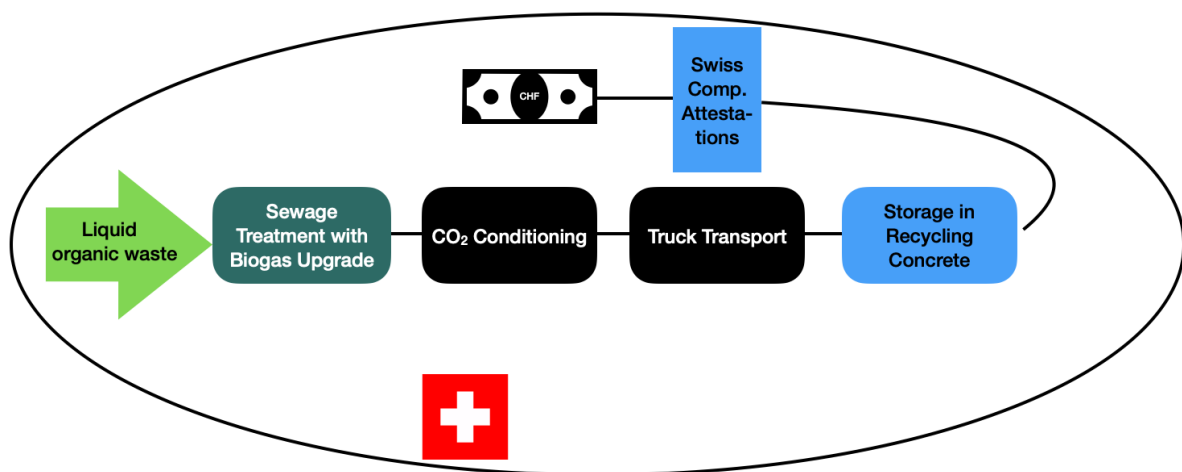


Figure 2: The value-chain and monetisation option detailed in this blueprint.

2.3 Objective

The goal of this blueprint is to answer:

'How can Swiss project developers of biogas upgrading projects with CO₂ capture and storage in concrete generate revenue based on the mitigation results of their activities in carbon markets and beyond?'

While the blueprint explains primarily the approach under the Swiss domestic compensation instrument it also addresses how alternative paths to monetisation deviate from it. This includes the Voluntary Carbon Market, authorisation of VCM credits for transfers under the Paris Agreement Article 6.2, generation of credits under the UN Article 6.4M and implications of emissions trading systems (ETS).

The Swiss compensation instrument is the starting point. However, the process is also explained for the VCM as there is a broader ensemble of VCS methodologies. The VCS may also allow the use of those methodologies for quantifying emission reductions and removals results in other carbon crediting and results-based systems that are not intended for voluntary purposes.

Blueprint 1 – Domestic CCUS value chain

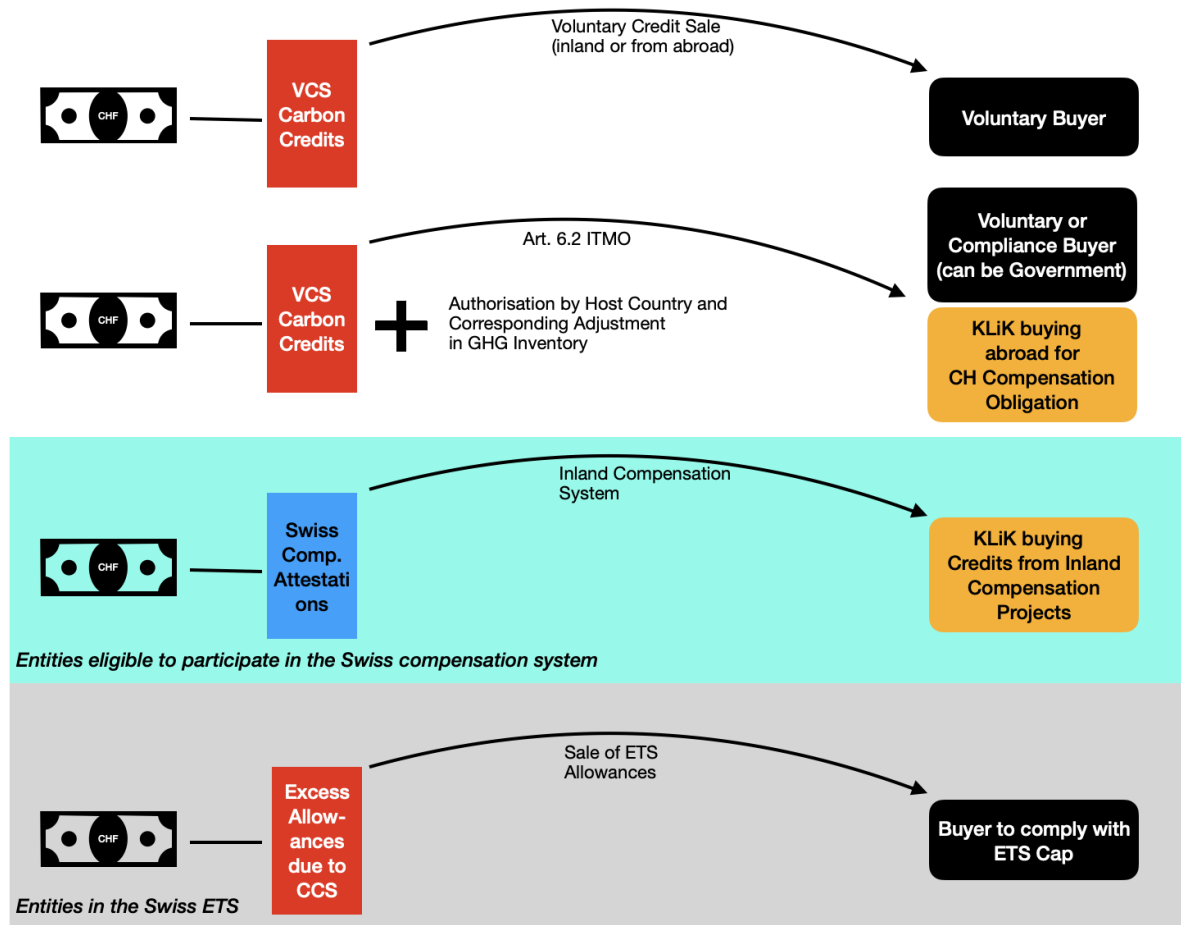


Figure 3: Overview of the four possible avenues of monetising mitigation results examined in the four blueprints; the focus of this blueprint is on the third approach - highlighted in blue

2.4 Materials and methods

This blueprint draws primarily on the official documents and regulations pertaining to the Swiss domestic compensation system as well as the VCS Methodology Concept Note on Carbon Capture Utilisation and Storage. Secondly, it refers to the VCS baseline and MRV methodology for CCUS, which holds some information likely to apply partly also to CCU, the CCUS transport module and two accompanying tools which could be applied within the VCM. These were developed by Perspectives and South Pole with input from stakeholders from CCS+ and DemoUpCarma. Thirdly, the blueprint also draws on pertinent provisions in the contexts of national GHG inventories, EU storage rules and EU carbon certification considerations, as well as the UNFCCC Article 6.

3. Description of the value-chain use case

CCUS projects involve the capture of CO₂ from a point source or directly from the atmosphere. The captured CO₂ is typically compressed and transported by pipeline, ship, rail or truck to be injected into deep geological formations (e.g. deep saline aquifers, depleted oil and gas reservoirs, or reactive rock formations). Alternatively, CO₂ can be stored in the long term in building materials.

3.1 Description of the Scope of Activities

The domestic value-chain case example outlined by this blueprint includes the collaboration between a Swiss entity capturing CO₂ at a biogas upgrading facility, the transport of CO₂ within Switzerland via trucks, and the CO₂ utilisation in concrete for durable storage.

A key aspect of developing and describing a carbon project (as shown in section 4) is determining its boundaries in time and space. The following table outlines how this could look like in the case examined here.

Table 1: Project boundary

Geographical boundary	Refers to the location of the project activities.	Switzerland
Temporal boundary	Refers to the timeframe during which the project activities occur and impact GHG emissions.	The temporal boundary for this project type is unclear to date: it will be determined by the crediting period multiplied by the max. allowable renewal (in the final CCUS methodology). ²
GHG sources	All relevant sources of GHG emissions are identified and included within these boundaries.	Biogas upgrading facility, conditioning leakage, transport leakage, energy required for conditioning, transport, and storage, cement plant leakage.
Secondary effects³	The project boundary also considers secondary effects related to the project.	Secondary effects could include emissions associated with a relative increase in conventional, less expensive, concrete production.

(Source: Authors, 2023)

² In case of projects involving geological storage of CO₂, the maximum project duration under the VCS is 42 years (7 years crediting period, renewed for up to 5 times). The higher (chemical) durability of binding CO₂ in cement may result in even more favourable provisions in the CCUS methodology.

³ Most methodologies foresee a materiality threshold that allows cutting off secondary effects of irrelevant size to avoid unnecessary complexity.

One example of biogenic sources in Switzerland is liquid waste. Biomass upgrading using liquid waste represents a relatively small CO₂ point source and is broadly spread throughout the country. The liquid waste sector deals with hundreds of thousands of tCO₂. The scale is small compared to other sectors in Switzerland, such as cement or waste incineration. Furthermore, they deal with biogenic CO₂, which is currently considered climate-neutral and is typically not in high demand for other uses. However, following Switzerland's climate goals, especially towards negative emissions, biogenic sources of CO₂ might play a crucial role in the future. Here, the liquid sector and other biogenic sources, such as biogas plants from digestion, are worth taking into consideration.

This blueprint describes the CCUS value chain of the capture of biogenic CO₂ emissions from a biogas upgrading plant, with domestic transport via trucks and CO₂ utilisation in concrete.

3.2 Technical feasibility and barriers

The separation of CO₂ from a biogas mixture using membranes, as well as the liquefaction of CO₂, are established processes widely used in the biogas and chemical industries. The technology to store CO₂ in concrete for construction material production has been applied and proven with various partners in the cement sector and at various sites. Operationalisation challenges remain open. Although they may not be critical individually, they can cumulatively complicate the smooth implementation and management of such activities, especially when involving new partners.

As a purely domestic project, this type of activity also avoids the complications related to transboundary transport of CO₂ regarding accounting and ownership of credits. As of now, biogenic sources of CO₂ are not included in any compliance scheme, nor are they planned to be in the near future. This facilitates proving additionality for their consideration under the VCM or the Swiss compensation scheme.

4. How to generate and monetise credits under the VCM

The VCM has grown in recent years and offers a meaningful source of revenue for climate mitigation results. VCM involves the sale of carbon credits, which can be bought for voluntary offsetting, voluntary (non-offsetting) mitigation contributions, or, in some cases, also for offsetting obligations (if additional requirements are met). Credits are issued through a formal process by standards such as the VCS, which can be traded directly or through intermediaries. Though often used to make carbon neutrality claims, they increasingly serve more broadly as a means to track mitigation results in a consistent and verifiable manner.

The process of generating carbon credits essentially serves to transparently demonstrate that the conditions for integrity are met by the proposed activity. The integrity of carbon credits requires transparently meeting the seven factors shown in Figure 4.

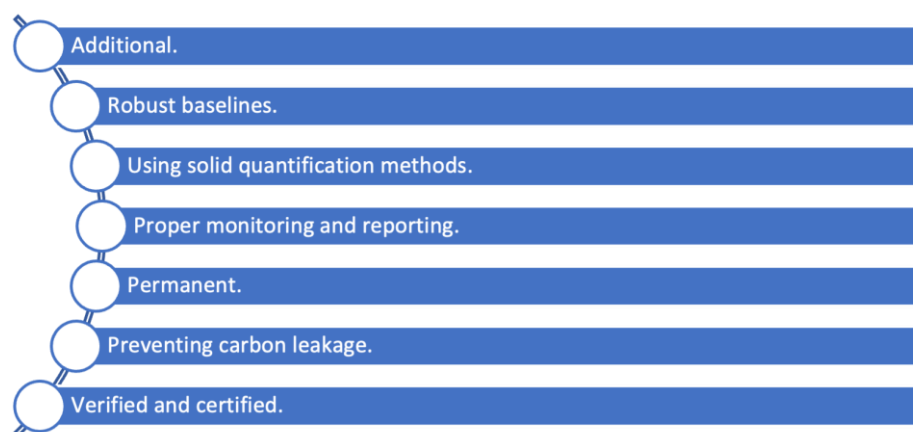


Figure 4: Criteria relevant to the integrity of carbon credits – to be demonstrated transparently by the standard

(Source: Authors, 2023)

Methodologies are vital for quantifying greenhouse gas benefits, generating credits and monetising them in the VCM. These methodologies are regularly updated for accuracy and relevance. For this, specific methodologies have been developed under a voluntary carbon market standard – in our case, under the VCS. For the case examined here, the Methodology for Carbon Capture and Utilisation and Storage is relevant along with the following modules: CO₂ capture from biogenic sources, Consolidated Module for CO₂ Transport, and utilisation of CO₂ in concrete (Figure 5).

Besides the overarching methodology and value-chain specific modules, the use of the tool for baseline quantification and allocation of project emissions in projects with VCS and non-VCS- CO₂ flows is further required if the CO₂ captured in the biogas facility is mixed with CO₂ from other sources before being utilised in concrete (see Figure 5). This is needed to differentiate between the CO₂ from VCS and non-VCS project activities, as CO₂ leaving the project boundary (i.e. non-VCS CO₂) must be quantified and excluded from the project's emission reductions or removal results that may be credited in the VCS.

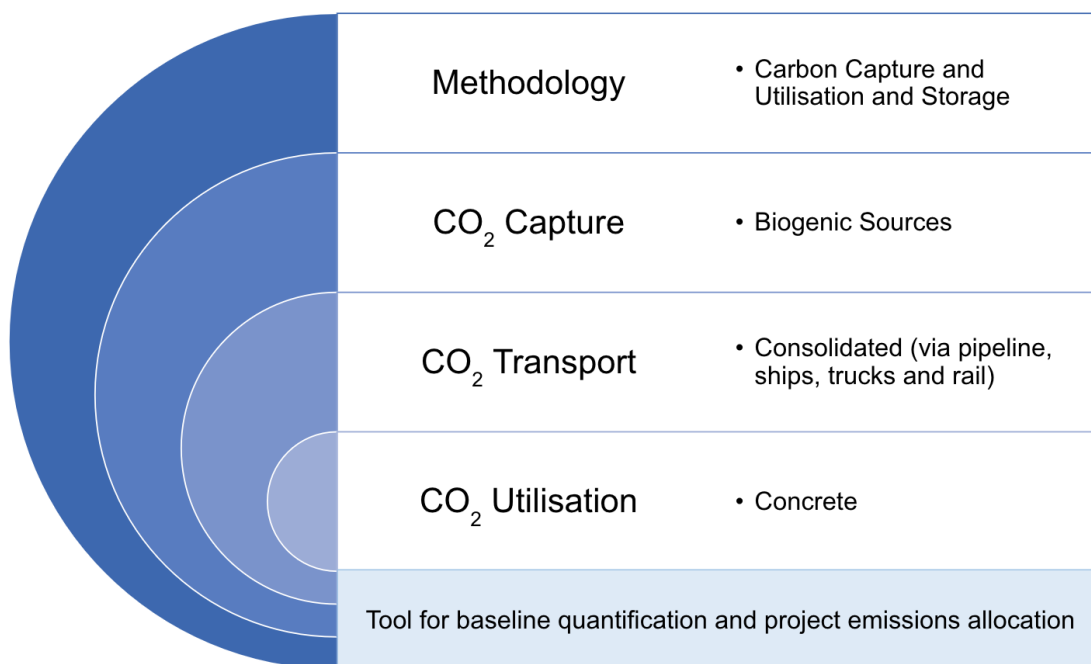


Figure 5: CCUS Methodology, its modules for capture, transport and utilisation and accompanying tool applicable in this blueprint

Step 0. Preparations for a domestic CCUS value chain

The complexity of CCUS value chains requires a number of measures even before formally starting the carbon project development under a specific standard. This notably includes figuring out the most suitable institutional arrangement along the value chain, including signing agreements to meet VCS requirements, including the 'Geologic Carbon Storage (GCS) Requirements' (Verra, 2023b) The GCS is the key tool for ensuring inter alia that the entity receiving credits is also held responsible should reversal occur.

Another important tool that may be considered at the outset is the Non-Permanence Risk Tool (NPRT)(Verra, 2023a), which offers an evaluation of reversal risk. Early consideration of reversal risk may help structure contractual arrangements for dealing with the consequences of reversals among value-chain partners should it occur later on (e.g. to avoid unduly placing the financial burden on certain partners or failing to ensure appropriate incentives for the partner responsible for storage).

Alternative modes of collaboration should also be considered: For example, instead of choosing one of the partners in the value chain to act as project proponent and project developer, Partners could form a legal entity for the purpose of developing the carbon project. A third model is that an outsider-professional project developer acts as a project developer on behalf of the value-chain partners, which can offer the advantage that in some cases such a project developer takes on the financial cost and risk of the project development itself.

Step 1. Activity design

The process, as demonstrated in the example of the VCS, is very similar to the Swiss domestic compensation system in most regards and is often referred to as 'the carbon project cycle'. The

Blueprint 1 – Domestic CCUS value chain

process for carbon credit issuance typically begins with a PDD submission by the activity developer. This document outlines the activity, baseline and monitoring methodology. An independent third party validates the activity before registration. Once operational, the developer monitors and reports emissions reductions as per the PDD. The outcomes are then independently verified for carbon credit issuance.



Figure 6: The carbon project cycle from idea to issuance of credits

(Source: Authors, 2023)

This is the most work-intensive phase for the project proponent. It culminates in the preparation of a Project Design Document (PDD), which captures all relevant information as required by the methodology (including for additionality demonstration, baseline identification and the monitoring plan). PDDs serve a key role up to validation as they demonstrate a proposed project's compliance with the conditions for integer carbon projects (see Figure 4). The PDD's core elements are shown in Figure 7.

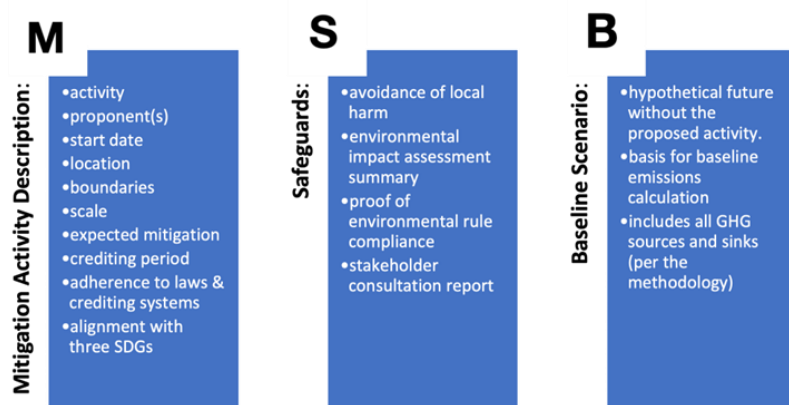


Figure 7: The core elements of a project design document (PDD)

(Source: Authors, 2023)

A central element in developing the PDD is the definition of the project boundaries, which is particularly challenging in the case of CCUS activities; while in the simplest cases, the project comprises of a single capture, transport and storage facility, it is also possible that multiple capture facilities are included through a shared storage facility, or vice-versa that CO₂ captured from a single site is stored at multiple sites. For all these processes, the project boundary includes electricity, fuel, and material inputs as well as their associated emissions – including venting and fugitives.

Blueprint 1 – Domestic CCUS value chain

Another key piece is the setting of the baseline, which in the case of adding carbon capture (for storage) to an existing biogas upgrading plant essentially assumes a continuation of CO₂ emissions into the atmosphere. The baseline emissions can be determined by the amount of CO₂ mineralised into concrete.

As part of the PDD, the proponent will need to demonstrate additionality. Additionality is present if, without the incentives from carbon credits, the mitigation activity would not occur, and thus no emissions reductions or removals would be realised. Additionality is crucial to maintain environmental integrity and ensure efficient use of funds for climate change mitigation. Its proof needs to be provided following the guidance of the CCUS methodology in three steps, based on investment analysis: 1) Regulatory Surplus, 2) Implementation Barrier and 3) Common Practice – i.e. to demonstrate that the project is delivering mitigation beyond regulatory requirements, that a financial barrier is in place and that the activity is not (yet) common practice. Projects that pass all three of these steps are considered additional. For a pre-defined set of carbon-dioxide removal (CDR) technologies, the CCS+ Initiative aims to develop an alternative approach to demonstrating additionality. While a demonstration of the regulatory surplus will remain in any case, an alternative approach to the investment analysis, e.g. through a positive list, will be elaborated in the future.

In the PDD, the proponent will also need to present the monitoring plan. This plan anticipates the monitoring activities that will be required during the monitoring period. It indicates the physical equipment to be used (e.g. meters), and the responsibilities and processes for collecting, processing and reporting data, as required by the methodology. It defines the parameters that need to be measured, their accuracy and the measurement frequency.

Step 2. Validation

Upon submission of a PDD by the project proponent to the standard body, the validation process starts. It involves a VVB – approved by the carbon credit standard – which independently checks if the proposed project meets the standard's requirements. The first step of validation is a public review for about a month, followed by desk evaluation and then a site visit by the VVB. Based on these inputs, the VVB examines the accuracy of claims in the PDD, and either recommends the project for registration or suggests changes before it can be registered.

Step 3. Registration

Upon validation, the carbon standard does a completeness check and registers the project in its registry. This will enable the project owner to generate carbon credits for an initial period, called the crediting period. The length of the crediting period is set by the standard and can vary for different project types. The crediting period for this project type is unclear to date: it will be determined by the crediting period multiplied by the max. allowable renewal (in the final CCUS methodology).

Step 4. Monitoring and reporting

Upon registration and the start of activities, the MRV of results starts. A monitoring report is prepared following the data and information requirements set out in the latest VCS requirements for geological carbon storage and the respective methodology and modules. If a loss of containment occurs, the procedures outlined in the VCS Program (Verra, 2023c), the GCS requirements and the GCS NPRT shall apply.

Step 5. Verification of results

The report is verified by a VVB and the project proponent can then file a credit issuance request to the carbon standard.

Step 6. Issuance of credits

If everything is in order, credits will be issued in the registry and transferred to the proponent's account. Active credits can then be sold to gain revenue.

Step 7. Sale of credits

There are two key types of buyers: intermediaries/market aggregators, and end users. The latter include individuals, businesses and governments, but for project proponents with a small portfolio, they will be difficult to reach. Intermediaries include brokers, traders and exchanges (e.g. Carbon Trade Exchange (CTX), the CME Group and Xpansiv), which tend to charge a fee ranging from 5% to 20%. The sale can happen either before credit issuance (via an Emission Reduction Purchase Agreement (ERPA)) or after issuance. ERPAs under the VCS follow a template (IETA, 2023), which establishes roles, rights and responsibilities regarding project risks besides price, amount and credit delivery timeline. Another option for project initiators is partnering with activity development partners, who accompany the project from its inception to issuance and in some cases front the associated expenses to in turn be remunerated with a portion of credits generated later.

Removal-based credits are expected to fetch a higher price than those representing emission reductions, especially those that can demonstrate durable storage.

4.1 CCUS methodology beyond CCS+ Initiative

Unlike other alternatives, the CCS+ carbon accounting infrastructure offers a unique modular 'plug-and-play' system approach to properly incorporate a wide set of possible project configurations. The aim is to include the majority of the current CCUS activities, and by addressing each technology type separately, future solutions can be effectively integrated into the infrastructure.

Today technology and industry players in the CCUS space offer a wide range of carbon capture, transport, utilisation and/or storage solutions. All these solutions need to be addressed and accounted for in their unique way. Methodologies are usually focused on specific technologies or define a set of eligible activities. This potentially leads to mitigation activities from one emitting sector not being eligible under the same accounting methodology due to different use of technologies or project activities. This is where the CCS+ initiative accounting structure would come into play.

In addition to the methodologies developed by the CCS+ Initiative under the VCS, various other carbon standards are actively working on the development of robust accounting methodologies to tackle the diverse and complex topic of CCUS. This section offers an overview of methodologies available or under development, specifically concentrating on carbon standards endorsed by the International Carbon Reduction and Offset Alliance (ICROA)⁴.

⁴ ICROA collaborates with various stakeholders in the voluntary carbon market, including project developers, carbon standards, and businesses seeking to offset their carbon emissions, promoting high standards and best practices in the voluntary carbon market. It ensures measurable, permanent, additional and independently verified emissions reductions.

Blueprint 1 – Domestic CCUS value chain

In this blueprint, the project value chain deals with the capturing of biogenic CO₂ from a biogas upgrading facility with subsequent transport via trucks and long-term storage in concrete. Depending on the specific technologies used in the project design, these activities could potentially be covered by methodologies published by the Gold Standard (GS), Puro.earth (Puro), and the VCS⁵.

Gold Standard (GS)

Often considered the ‘gold standard’ of carbon standards, GS favours high-hanging fruits in the VCM and is known for having robust stakeholder consultation, safeguarding and sustainable development goal (SDG) requirements. The methodology is applicable for project activities aiming at sequestering CO₂ in demolished concrete aggregates (Gold Standard, 2022). It involves the capturing of biogenic CO₂ from direct air capture (DAC) or a diverse range of biogenic sources including the separation of CO₂ and methane at a biogas upgrading facility. The means of CO₂ transport is limited to trucks. The final sequestration of CO₂ is tied to a specific direct or indirect mineral carbonation technology. While GS covers the project value chain of this blueprint, it has to be seen, if the potential project developer can meet the technological requirements as described in the methodology. Here, a detailed assessment of the specific project design would need to be done.

Puro.earth (Puro)

Puro is focussed solely on removals, technological/industrial or nature-based. Its methodology addresses CO₂ removal through the chemical binding of CO₂ in carbonated materials (Puro.earth, 2022). The sequestration and storage of CO₂ sourced from DAC or any other biogenic source is eligible in any solid material which includes metal carbonates such as CaCO₃ and MgCO₃. The methodology does not specify the mode of transport. With this broad approach to eligible project activities, Puro allows the majority of technological solutions and potential project developers to be eligible under their methodology. This is attractive to early movers and providers of novel technologies as they can develop their projects and monetise their activities under the VCM.

Verified Carbon Standard (VCS)

The VCS, as the world's most widely used GHG crediting program, has developed a CCUS methodology before the efforts undertaken by the CCS+ Initiative. This methodology focuses on CO₂ utilisation in concrete production (Verra, 2021). Unlike the other two methodologies, here the focus is on waste CO₂ which would have otherwise been emitted to the atmosphere and DAC. The CO₂ is not limited to a transport mode. CO₂ reductions are archived by sequestering waste CO₂ in their ready-mix concrete and further reducing emissions by requiring less cement during the production process. Similar to the GS methodology, a detailed assessment of the specific project design and technologies needs to be done, to evaluate its eligibility under the VCS methodology.

Generally speaking, all standards, which are discussed in this blueprint, follow the same complex goal of developing rules, requirements and procedures for the design, development, monitoring and reporting of carbon projects which then results in an emission reduction or removal. Yet, when examining individual technology groups and solutions in isolation, rather than considering the entire value chain as a whole, the CCS+ initiative can craft a more robust carbon accounting mechanism for diverse project value chains.

⁵ Not related to the CCS+ Initiative.

4.2 Use of VCM credits or dedicated crediting for use under Article 6.2

Under the Paris Agreement, countries can cooperate to achieve their NDCs based on the authorised transfers of ‘mitigation outcomes’ (which then become ITMOs). ITMOs can also be used towards obligations on international aviation under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

Authorisation as a precondition for ITMO transfer requires that the party from which the credits originate apply a so-called ‘corresponding adjustment’ (CA) to its GHG inventory. It is important to highlight that CAs do not alter the national GHG inventory but rather serve as adjustments to the emission balance, reflecting the emissions source under NDC targets. When a country uses the ITMO to achieve NDC targets, the buyer country also applies CA in its inventory. In most cases, ITMO transfer will rely on crediting via an established VCM standard, but countries can in principle also develop their own crediting systems if both buyer and seller countries agree on the requirements. Credits authorised as ITMOs have a broader demand base, including governments, airlines and voluntary buyers, and are likely to fetch a higher price. Credits without CA are increasingly seen as unfit for compensation and carbon neutrality claims, meaning that over time voluntary buyers will be willing to pay a premium once CA and ITMO transfers are operational at national and UN levels in one to two years.

Switzerland and other countries are already engaging in purchasing contracts with entities abroad – and with their respective governments – to determine quantities, conditions and responsibilities for carbon credit generation and ITMO transactions.

5. Swiss compensation scheme

The Swiss compliance scheme is driven by the mandate outlined in the country's CO₂ Act (Federal Assembly of the Swiss Confederation, 2011), which requires fossil-fuel importers to offset a specific portion of their emissions. To meet this legal obligation, the KliK Foundation acts as an intermediary, connecting fossil-fuel importers with emission-reduction projects⁶ that generate carbon credits. These carbon credits from the approved projects are sold to fossil-fuel importers to offset their carbon emissions. The compensation scheme distinguishes between domestic projects within Switzerland and those undertaken abroad. The compensation obligation is defined as a specific percentage of the overall emissions produced by the imported fuels, which have to be offset partially in Switzerland and internationally. For a more in-depth exploration of the Swiss domestic compensation scheme and further details on additional CCUS activity support funded by unused funds from KliK's predecessor, the Climate Cent ('Klimarappen') Foundation, please refer to a separate document developed under the DemoUpCARMA project (South Pole, 2023).

This chapter is dedicated to providing prospective CCUS project developers in the value chain outlined in this blueprint with insights into procedures for establishing a CO₂ compensation project under the Swiss compliance scheme. The chapter describes aspects of project development, which share similarities with developments in the VCM. Nevertheless, within the compliance scheme, several processes and structures are different (e.g. relevant documents around the registration of a climate project). Under the VCM, a clear distinction is drawn between a methodology and a project development. While a methodology defines standardised rules for executing, monitoring and verifying emission reductions, ensuring consistency across projects, the PDD describes unique project-specifics that apply a methodology, detailing project specifics and serving as evidence for each individual carbon offset project. In the Swiss compensation market, these essential documents are combined into a joint project description and a monitoring plan. Nevertheless, they all include critical elements such as additionality, baseline definition, MRV processes, system boundaries, leakage and conservative CO₂ reduction quantifications. Unlike the VCM, where project proponents can potentially apply an existing standalone methodology to their project, Swiss compensation mechanisms require the development of all relevant documents for each project.

Another notable feature of the Swiss compliance scheme is the compensation obligation imposed on the KliK Foundation. Securing Swiss 'attestations,' hereafter referred to as carbon credits, is subject to negotiations with project developers. It is essential to recognize that buyers in the voluntary market may also become potential purchasers of these credits. Typically, project proponents engage in ongoing discussions with KliK throughout the registration process with FOEN. A process, detailed later in this chapter, such as the option to have a 'project outline' document evaluated by a third-party validator and verifier (VV), provides an initial estimate of certificate quantities and the project's likelihood of acceptance and registration. Early discussions will be relevant for financial assessments during project development.

The following chapters provide an overview of the registration process for the chosen CCUS project value chain, while also highlighting requirements and general principles. For an in-depth description, please refer to the document provided by FOEN (FOEN, 2022). The provided overview and information on the Swiss compensation scheme are extracted from the same document.

⁶ The Swiss compensation scheme allows the development of single projects or programs that group several activities with common purposes. For simplicity, this document only refers to projects.

5.1 Procedure towards carbon credits

In the Swiss compliance market, the procedure for generating carbon credits closely mirrors the carbon project cycle previously outlined for the VCM, as depicted in Figure 6. Figure 8 provides a visual representation of the application process (Steps 1 to 3), and the ongoing monitoring, verification and transfer of carbon credits (Steps 4 to 6). In addition to these six steps, the figure emphasises the various documents that require authorisation, validation or verification by the involved stakeholders. In our project example, these stakeholders include FOEN in Switzerland, a VV (a third-party validator, similar to a validation/verification body (VVB) in the VCM in Switzerland as the host country and all partner countries within the CCUS value chain.

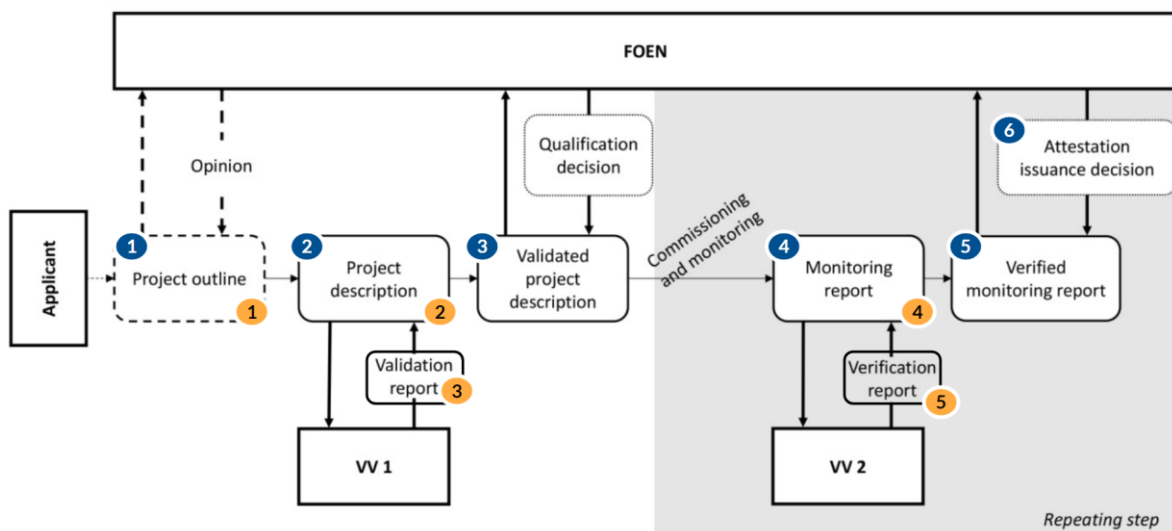


Figure 8: Swiss compensation scheme procedure (blue circles indicate carbon project cycle steps; orange circles indicate relevant project development documents⁷ necessary for application and ongoing monitoring, verification and credit issuing cycles)

(Source: adapted from FOEN, 2022)

Step 1: Project outline (optional)

In the first optional project outline, the developer can submit a project outline document to the FOEN. This document serves as a preliminary assessment and provides a first eligibility judgment. Critical issues include additionality, differentiation from other climate policy instruments and preliminary calculation of expected emission reductions.

Step 2: Project description and validation

A detailed project description includes the following information: A detailed project description, an economic feasibility analysis, reference scenario development, differentiation from other climate policy instruments, a calculation method for determining emission reductions, a monitoring plan, and the validation report. The validation report is the revision of the project description by a FOEN-approved VV.

⁷ Procedures and templates for project development can be found on FOEN's website (FOEN, 2023).

Blueprint 1 – Domestic CCUS value chain

Step 3: Qualification decision

After the VV approves the project description with a validation report, the project developer receives a qualification decision. With the authorisation, the project is eligible to commence the annual, ongoing Monitoring, Reporting, and Verification (MRV) process.

Step 4: Monitoring

The project description defines the start date for monitoring emissions and the method for demonstrating emission reductions. Typically, monitoring begins when the project becomes operational. The monitoring report demonstrates the emission reduction according to the monitoring plan outlined in the project description for each year. The monitoring report has to be annually verified by the VV.

Step 5: Approval by FOEN

The verified monitoring report must be approved by the FOEN.

Step 6: Attestation issuance decision

After the attestation issuance decision has been taken, carbon credits are transferred to the KliK Foundation.

5.2 Eligibility of the proposed CCUS project value chain

As of the revision to the CO₂ Ordinance in June 2022 (Federal Assembly of the Swiss Confederation, 2012), CCUS projects involving long-term storage in biological or geological formations, or non-organic building materials (e.g. concrete) have become eligible for the generation of carbon credits within the Swiss domestic compensation scheme.

All project developers need to set up a project description which will assess the eligibility of the proposed project in detail (Step 2 of the carbon project cycle). Below, several issues relevant to the specific project value chain described in this blueprint are discussed.

Compliance with applicable legal provisions, differentiation from other climate policy instruments and avoidance of double-counting

Similar to projects in the VCM, this blueprint's project case must demonstrate compliance with other relevant legal provisions, and differentiation from other climate policy instruments and must avoid double counting. For instance, if future regulations were to mandate CO₂ capture from biogenic sources to achieve the goal of removing 2 million tonnes of CO₂ per year by 2050, it would not be possible to generate carbon credits within the Swiss compliance market. The same applies to the emission coverage under the ETS; if biogenic CO₂ emissions were covered in this trading scheme, these project activities would also not be eligible under the Swiss compensation market. Currently, no climate policy instruments are set up which would interfere with the development of project activities with biogenic CO₂ being stored in concrete or concrete-related products such as aggregates. Project activities described in this blueprint most likely would be situated in the cement industry, which is included in the ETS. As of today, biogenic CO₂ is not covered by the trading scheme and, therefore, would not hinder the eligibility of carbon credit generation under the Swiss compensation scheme. However, several companies dealing with such CCUS activity claim that the process of CO₂ utilisation in concrete or a concrete-related product has a secondary substitution effect of reducing the need for the use of clinker during concrete production. This substitution

effect could not be claimed, and the generation of carbon credits would not be eligible under the Swiss compensation scheme, as the ETS covers these CO₂ emissions.

Permanence of carbon storage

Under the Swiss compensation scheme stated in the CO₂ Ordinance (Art. 5 para. 2), projects need to demonstrate a CO₂ storage of at least 30 years, regardless of the project duration and including after completion of the project. Project activities dealing with CO₂ utilisation and storage in concrete structures can meet this requirement because duration requirements for concrete structures usually range from 50 to 100 years (Müller et al., 2014). Additionally, a Non-Permanence Risk Tool offers an evaluation of reversal risk (Verra, 2023a). This risk tool is already available for CCS projects and is currently under development for projects involving CO₂ utilisation for durable storage, including mineralisation in products, such as the described activities in this blueprint.

Demonstration of additionality

Additionality under the Swiss compensation scheme is demonstrated by providing evidence that the project would not be economically viable without the revenue from the carbon credits for the entire duration of the project^{8,9}.

This can be shown in one of the following ways:

- Simple cost analysis: If a project has no other revenue streams apart from the sales of the carbon credits, a simple cost analysis is used. Demonstrating that the project is not profitable and less viable than the most likely alternative scenario.
- Investment comparison analysis or benchmark analysis: Key financial indicators such as NPV or IRR are compared between the project scenario and the alternative scenarios. An additional sensitivity analysis is done, to demonstrate the financial assessment is robust when assumptions are adjusted.

To analyse the economic viability, all costs and income streams need to be compared between the reference scenario and the project scenario. In our case, the substantial investment cost for a capture unit and a utilisation plant and ongoing operational cost for both activities would need to be covered by the revenue by sales of concrete products alone to deem the project ineligible under the Swiss compensation scheme. Considering the reference scenario, in which neither CO₂ capture nor transport and utilisation in concrete takes place, the project scenario is very unlikely to be financially viable.

In addition to the economic analysis described above, the project developer must show that the project is not common practice. CO₂ capture followed by mineralisation in concrete is still a relatively rare practice. The significant initial capital required for CO₂ capture and mineralisation facilities presents a substantial barrier. Further research, development, and financial support are needed for the successful integration of this technology.

⁸ It is essential to include all types and sources of revenue. These include development assistance from donors, other climate finance mechanisms, public funding or other non-refundable payments.

⁹ The economic feasibility analysis is based on UNFCCC's Tool for the demonstration and assessment of additionality (UNFCCC, 2012).

Possible project duration

The Swiss compensation scheme, which obligates fuel importers to offset a portion of their emissions, was established based on the CO₂ Act. This legislative framework is in force until the end of 2030. However, without subsequent follow-up legislation, fuel importers will no longer be bound to offset their emissions from 2031 onward. Consequently, project developers are left with no assurance that this revenue stream will continue to exist. The lack of certainty regarding the sale of carbon credits under the Swiss compliance scheme significantly diminishes the appeal of CCUS project development. Such projects entail substantial upfront investment costs and correspondingly extended amortisation periods, making them especially unattractive under these circumstances.

Determination of reference scenario

The reference scenario is the most likely alternative to the project scenario, generally being the most economically attractive scenario. A reference scenario is defined once at the beginning of a project and is later compared to the measured project scenario to quantify the emission reductions and ultimately determine the amount of issued carbon credits.

In this blueprint, we can consider potential reference scenarios regarding the capture of biogenic CO₂ on a biogas upgrading plant and the utilisation of CO₂ in concrete. These scenarios are interconnected in the sense that the absence of captured CO₂ would also mean no CO₂ utilisation.

The most likely reference scenario for the capture of biogenic CO₂ is the current business-as-usual case. Biogenic CO₂ is released into the atmosphere due to the absence of regulations and the high investment cost of a capturing unit and the operational costs associated with it. A mandatory capture of these types of emissions also seems unlikely due to the already-mentioned costs and the general concept of biogenic CO₂ being climate-neutral and as part of the natural carbon cycle, it does not contribute to a long-term increase in atmospheric CO₂ levels.

For the utilisation and storage part of the project value chain, the most likely reference scenario is again the business-as-usual case. Due to its novel technology approach, as well as the corresponding investment costs a mandatory utilisation of CO₂ in cement is highly unlikely. As the cement industry is already covered by the ETS, and biogenic CO₂ is not in the scope of any legislation.

For both cases, a reference scenario, in which the costs of the project activities reduce drastically and the project scenario becomes economically viable can be ruled out for the time until the compensation obligation discontinues at the end of 2030.

Monitoring plan, monitoring report, and quantification of emission reductions

The monitoring plan, a crucial component of the project description and initial authorization process, outlines all relevant parameters and data to be measured and reported throughout the project's lifecycle. It provides specific requirements for handling data and methods employed to calculate emission reductions. This comprehensive monitoring plan serves as a step-by-step guide, enabling project proponents, third-party validators, and the FOEN to precisely calculate and understand actual emission reductions in the yearly monitoring report. In cases where a parameter cannot be measured precisely, the estimate must be as accurate as possible, which requires the consultation of supporting scientific measures. Moreover, all emission reductions or parameter estimations must be made conservatively, following the principle of conservativeness, to prevent any overestimation. The yearly monitoring report, verified by the VV and the FOEN, calculates emission reductions for a given year by deducting project emissions and associated project leakage¹⁰ from the reference scenario.

¹⁰ Leakage refers to the change in emissions beyond the project activities that are not directly attributed to but influenced by the project. It can have either a negative impact, resulting in increased emissions, or a positive impact, leading to more emission reductions. Unless negligible, leakage emissions must be considered in the final emission reduction calculation. An example of leakage would be the necessity to offset the reduced energy output and increased use of fossil fuels due to the diversion of biomass from a waste incineration plant to a biogas plant.

6. Swiss emissions trading system

The Swiss Emissions Trading System (ETS), which is linked to the supranational ETS of the European Union, can incentivise CCUS of those entities that are subject to it. The waste sector (neither solid nor liquid) is not currently subject to the ETS, so this system does not presently allow for the monetisation of CCUS activities. The liquid waste sector does not appear slated for inclusion in the ETS presently, but this might nonetheless change in the medium-term future and within the multi-decadal project durations of CCUS carbon projects. The municipal solid waste sector, for example, appears a likely candidate for inclusion later this decade.

The ETS nowadays only represents a marginal consideration for liquid waste-sector activities. However, the possibility of inclusion should be taken into account when pursuing biomass-upgrading-CCUS carbon projects. A future inclusion of the liquid waste sector would have several important implications: it would halt the eligibility of all activities flowing from liquid waste CO₂ capture under the Swiss compensation system and likely undermine the additionality of VCM credits, thus also halting the renewal of the crediting period.

The cost associated with operating the CCUS value chain would then fall on the plant operators, though they may also benefit from free allowances. The inclusion would ultimately open the possibility of overachieving the allocated cap (through CCUS operation) and, consequently, selling excess allowances, thus again generating carbon revenue based on the removal results achieved by biogas-upgraded liquid waste plants with CCUS.

7 EU Carbon Removal Certification Framework

Introduced as a component of the European Green Deal on 30 November 2022, the Carbon Removal Certification Framework (CRCF) represents an initiative of the EU Commission to enhance the tracking of carbon removal results in the EU. As the framework will only become operational in the coming years, the applicability to our case is uncertain and perhaps even unlikely. For example, the eligibility of entities outside the EU is unclear, especially when the full value chain takes place outside the EEA. Only if the CRCF is designed to allow for the generation of removal certificates in the European single market would our case potentially be eligible to generate removal certificates under the CRCF. Should this be the case, this could become an attractive alternative to Swiss Domestic Crediting in the medium to long term as credits produced in line with the CRCF might qualify for compliance use under EU regulations (perhaps including the ETS), fetching reasonably high prices.

8. Potential (future) crediting and monetisation options

International and national carbon crediting systems in most cases closely mirror the carbon project cycle outlined above. Carbon credits that are generated following the requirements of an ETS or a national carbon tax can also be monetised by selling to entities that need to demonstrate compliance with their cap or to reduce their carbon tax burden. In some cases, the regulator specifies eligibility based on: a) the types of credits, b) the specific voluntary carbon standard, c) the types of use, d) the carbon market segments, and e) further credit attributes (such as the vintage, host country and credit programme).

Monetisation towards compliance can – where possible – offer more favourable demand–supply ratios and price levels compared to demand on the VCMs. ‘Soft’ attributes, such as sustainable development co-benefits, can also influence credit demand and price.

8.1 Article 6.4 – centralised Mechanism

Though introduced via Article 6 of the Paris Agreement, Article 6.4 represents a standalone baseline and credit mechanism (A6.4M). It serves as a UN crediting mechanism fully under UN rules. It will follow a very similar carbon project cycle to that described previously, and methodologies under this mechanism may very much resemble those of established VCM standards. Credits (A6.4ERs) will be issued under the supervision of a UN supervisory body and will be internationally tradeable for countries to use towards NDC delivery (or voluntary offsetting or contribution claims). The A6.4M is expected to become the go-to source of credits for governments that need to purchase credits for achieving their NDC, which over time could become the largest source of demand for carbon credits. Given that the A6.4M has a unique position as a formal UN mechanism with UN-approved methodologies and requirements, it is expected to set the tone also for other crediting standards, which over time may adapt to become similar in their requirements.

8.2 ICAO – an emerging source of demand for credits

CORSIA was launched by the International Civil Aviation Organization (ICAO) in 2016. The main goal is to limit international aviation emissions to 2019 levels, and all participating airlines shall compensate for their emission increases with the purchase and surrender of eligible carbon credits. It is expected to be implemented in three phases: pilot phase 2021–23 (voluntary), first phase 2024–26 (voluntary) and second phase 2027–35 (mandatory).

Eligible standards include the VCS, American Carbon Registry (ACR), Clean Development Mechanism (CDM), Climate Action Reserve (CAR), Gold Standard (GS), China GHG Voluntary Emission Reduction Program, Architecture for Reducing Emissions from Deforestation and Forest Degradation and the Role of Conservation, Sustainable Management of Forests and Enhancement of Forest Carbon Stocks in Developing Countries (REDD+) Transactions, and Global Carbon Council (GCC). Not all credits are allowed from these programs, as several limitations have been defined. Limitations are set on the vintages of the activities (i.e. the crediting period must commence after 1 January 2016) or technology type. CORSIA is not expected to generate significant demand for eligible carbon credits during the pilot phase (IETA, 2022) due to the reduction in flights during COVID-19, but it may see greater demand in the first and second phases.

9. Barriers and opportunities for action

The purely domestic carbon project outlined in this blueprint faces fewer barriers than other approaches to monetizing CCUS, given that it primarily needs to comply with the domestic regulations and provisions for the Swiss domestic compensation instrument. As a novel type of carbon project involving numerous different and heterogeneous sector actors (liquid waste sector, transport, and the cement sector), it does, however, require developing the requisite basis for mutually beneficial cooperation along the value chain.

In particular, this means developing appropriate institutional arrangements that give clarity regarding ownership and revenue sharing. Developing a CCUS carbon project involves exploring and deciding on the most suitable institutional arrangement and drawing up the matching contractual arrangements so that there is an effective project developer (either one of the value-chain partners, an aggregate entity comprising of several partners, or a service-providing third party) and such that the requirements regarding reversal risk (as set out in the methodology and the reversal risk tool) are fulfilled.

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Blueprint 2a: International CCUS collaboration – Swiss solid waste CO₂ capture for storage in Norway

DemoUpCARMA

Work Package 5: addressing policy, regulatory and acceptance challenges to enable CCUS deployment

Task 1: emissions accounting, reporting tools and climate finance mechanisms of negative emissions for national and transnational CCUS solutions

Zurich, 15 Dec 2023

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Table of contents

1. Summary	5
2. Background and objectives	8
2.1 Challenges for monetising CCUS activities	8
2.2 Blueprint focus	9
2.3 Objective	10
2.4 Materials and methods	11
3. Description of the value-chain use case	12
3.1 Description of the scope of activities	12
3.2 Technical feasibility and barriers	14
3.3 Relevant information on the value chain for crediting and monetisation	15
4. How to generate and monetise credits under the VCM	16
4.1 CCUS methodology beyond CCS+ Initiative	21
4.2 Use of VCM credits or dedicated crediting for use under Article 6.2	23
5. Swiss compensation scheme	24
5.1 Procedure towards carbon credits	25
5.2 Eligibility of the proposed CCUS project value chain	26
6. Swiss emissions trading system	30
7. EU Carbon Removal Certification Framework	31
8. Potential (future) crediting and monetisation options	32
8.1 Article 6.4 – centralised mechanism	32
8.2 ICAO – an emerging source of demand for credits	33
9. Barriers and opportunities for action	34
9.1 Request clarification of eligibility of transboundary projects for Swiss inland compensation	34
9.2 International agreement to clarify where results occur	34
9.3 Institutional arrangements of ownership and revenue sharing	35
10. Bibliography	36

List of tables

Table 1: Project boundary	12

List of figures

Figure 1: Overview of the process for developing a ‘WtE-CO ₂ capture–international transport–storage’ value chain as a carbon project for generating and selling credits	6
Figure 2: The value chain and monetisation option detailed in this blueprint	10
Figure 3: Overview of the four possible avenues of monetising mitigation results examined in the four blueprints	11
Figure 4: Estimates of the respective contribution to total cost based on the similar example of KVA Lindth	13
Figure 5: Emissions occurring throughout the value chain for each tCO ₂ stored	14
Figure 6: Criteria relevant to the integrity of carbon credits – to be demonstrated transparently by the standard	16
Figure 7: CCUS Methodology, its modules for capture transport and storage and accompanying tools applicable in this blueprint	17
Figure 8: The carbon project cycle from idea to credits sold	19
Figure 9: The core elements of a project design document (PDD)	19
Figure 10: Swiss compensation scheme procedure	25

1. Summary

This blueprint explains how to generate carbon credits from a waste-to-energy (WtE) plant with carbon dioxide (CO₂) capture, utilisation and storage. It considers CO₂ capture at a WtE plant located in Switzerland and CO₂ storage abroad.

This document is part of a suite of four blueprints produced under the DemoUpCARMA project to aid the monetisation and scaling of carbon capture, utilisation and storage (CCUS)¹ applications in Switzerland under voluntary and compliance markets, both domestic and international. The blueprints collectively assess the following market cases:

- certificate sales via the voluntary carbon market (VCM)
- domestic compensation instrument under the Swiss compliance market
- international transfer of mitigation outcomes achieved abroad
- emissions trading systems (ETs)

and the following CCUS applications:

- CO₂ capture from a biogas upgrade plant, a WtE plant and a cement plant
- CO₂ transportation via trucks, rail, ships and barges
- CO₂ storage in concrete, subsurface supercritical CO₂ storage and subsurface mineralisation

To help project developers in their quest to monetise – and thereby enable – CCUS adoption, each blueprint presents:

- an overview of challenges for the monetisation of CCUS activities
- monetisation options for CCUS in voluntary and compliance markets
- step-by-step guidance to generate credits
- considerations for the monetisation of credits
- barriers and opportunities for action

This particular blueprint explains the specific steps needed, the implications of various crediting systems, and opportunities for immediate action towards crediting and monetising mitigation results from a CCUS value chain consisting of:

- CO₂ capture from a Swiss WtE plant
- CO₂ transportation via trucks, rail, ships and barges
- CO₂ storage in saline aquifer sub-seabed in an EEA country

It guides through the process to monetise such a CCUS activity (Figure 1), from establishing a partnership along the CCUS value chain to selling and sharing the revenue from the carbon credits generated.

¹ This report, exclusively uses the term carbon capture, utilisation and storage (CCUS) to cover any type of activities ranging from carbon capture and storage in geological formations to carbon capture, utilisation and storage in durable products resulting in long-term storage.

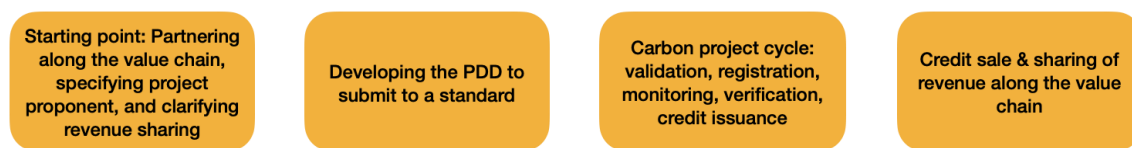


Figure 1: Overview of the process for developing a 'WtE-CO₂ capture-international transport-storage' value chain as a carbon project for generating and selling credits

(Source: Authors, 2023)

Carbon credits can provide a revenue stream to cover the additional cost of implementing CCUS technologies in the solid waste sector. Generating the carbon credits, however, is not straightforward. It involves complex procedures to ensure a high-quality standard and environmental integrity in the quantification and certification of emission reductions or removals through CCUS activities.

Used as a companion to formal documents setting out requirements and processes, this blueprint helps anticipate the main challenges for monetizing CCUS from a Swiss WtE plant involving international CO₂ transport and CO₂ storage abroad. It contains a step-by-step guide to submitting a project to a voluntary carbon market standard and demonstrating compliance with the standards' requirements. Key challenges even before submitting a project are explained, such as defining which entity (among many involved along the value-chain) will be the project proponent to whom credits will accrue and how to arrange for the appropriate sharing of carbon credit revenues among value-chain partners. With an example, the blueprint illustrates how to describe the project scope, i.e., how to determine the project boundaries in time and space, and the suitability of the activity with carbon accounting methodologies. This document discusses the considerations and requirements for project development within the voluntary carbon market (VCM). These aspects are systematically addressed in a designated Project Design Document (PDD). Under the framework of the Swiss compensation scheme, a corresponding document encompasses similar key topics such as the activity outline, baseline, and monitoring methodology. Complying with these requirements is crucial for meeting the Swiss compensation or VCM criteria and, more importantly, to ensuring a high-quality standard and high environmental integrity of the mitigation credits.

The blueprint, furthermore, provides guidance to navigate the evolving and increasingly complex carbon markets. Including key considerations for generating high-quality carbon credits under the voluntary carbon market that may become eligible also for some compliance markets. For this, the blueprint explains key considerations of possible developments regarding compliance markets, notably the implications of including the waste sector in the ETS and the potential to generate credits under Paris Agreement Article 6.2 and Article 6.4. Domestic compliance markets can provide diverse monetisation incentives, depending on the credits' eligibility for various uses. Upon becoming subject to the ETS (expected in the future for WtE plants), no credits are to be generated under the Swiss compensation system; nonetheless, the installation of CO₂ capture for permanent storage would still allow demonstrating mitigation results that reduce costs or allow selling surplus allowances.

Voluntary and international markets provide a wider set of opportunities for monetising CCUS activities. Should the waste sector be included in the ETS, CCUS-based VCS projects can continue

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to receive credits – if additionality can be shown – albeit likely at a reduced rate. Furthermore, new uses for CCUS carbon credits under nascent international markets can yield premium prices in comparison to purely voluntary markets. Reflections on expected market dynamics may help waste sector actors leverage carbon markets to responsibly upscale CCUS, to decarbonise their industry and achieve removals.

2. Background and objectives

Developing a CCUS industry is challenging: multiple interlinked sectors and actors need to cooperate based on the shared interest in generating revenue related to climate change mitigation results. This requires creating an ecosystem of compatible interfacing logistical, technological and contractual pieces working cooperatively across a significant number of private-sector actors and in compliance with carbon market rules, while also ensuring compliance with national accounting in multiple countries. Despite advancements in pilot value chains funded by subsidies or induced by regulatory obligations, transitioning to a scalable business model reliant on carbon revenue or incentives from emissions trading remains challenging.

CCUS activities involve multiple sectors, sparking concerns of power disparities between highly capitalised established oil and gas companies (delivering underground carbon dioxide (CO₂) storage) and much smaller and novel carbon capture technology providers. This requires attention to ensure fair sharing of carbon revenue among partners.

Currently, there are limited robust standards for tracking mitigation results from CCUS, despite relying on such results towards medium- to long-term mitigation goals. While initial CCUS pilot projects have accessed funds, scalable long-term funding for CCUS with clear climate benefits remains elusive. Effective climate action thus demands leveraging voluntary carbon markets (VCMs) to swiftly unlock revenue and draw lessons learned for regulatory approaches, many of which appear set to adopt key structures and methodologies from the first-mover VCM.

2.1 Challenges for monetising CCUS activities

This blueprint addresses two challenges:

- 1) the lack of methodologies for tracking mitigation results from CCUS, and
- 2) the lack of clarity on accounting, responsibilities and ownership in carbon market projects within the complexity of CCUS hubs and clusters.

Need for a cohesive ensemble of carbon-tracking methodologies

The absence of a unified carbon accounting methodology has hindered CCUS projects from accessing carbon markets effectively. Traditional methodologies have been narrow, focusing on specific project chains rather than the comprehensive industrial ecosystem needed for effective carbon management. This fragmentation has hampered the generation of reliable credits from CCUS projects, especially those in larger interconnected systems. However, recent efforts, led by the CCS+ industry consortium in collaboration with Verra (associated with the Verified Carbon Standard (VCS)), aim to develop a comprehensive suite of methodology modules to address this gap.

The CCS+ Initiative introduces an advanced carbon accounting system for varied CCUS projects, using a modular approach for activities across capture, transport, utilisation and storage. Its 'plug-and-play' system recognises shared infrastructures across CCUS technologies, enhancing adaptability to fit the numerous possible combinations across multiple hubs and clusters. The carbon accounting landscape had long been fragmented and lacked consistency across the emerging CCUS ecosystem. Though Verra and the Gold Standard have made progress, these standards would benefit from more stringent overall oversight to ensure long-term credibility via a

coherent carbon accounting framework that also conforms with evolving formal accounting rules under the Paris Agreement. High-quality, evolving methodologies can ensure transparency. Adopting stringent, up-to-date standards can streamline quality assurance, reducing costs and increasing efficiency throughout CCUS value chains. While this blueprint primarily emphasizes the carbon accounting landscape within the VCS, Section 4.1 offers an outlook of additional CCUS methodologies that assist early movers in securing revenue within the VCM.

Need for disambiguation of accounting, responsibilities and ownership

CCUS activities can achieve two different types of results, which need to be clearly differentiated depending on the source of carbon: reductions in emissions in the case of fossil carbon and removals of CO₂ in the case of biogenic carbon, which need to be transparently tracked and communicated. Other CCUS-specific ambiguities, particularly for CO₂ transport across national borders, can create confusion in regard to responsibilities that need to be clarified by private contracts among various partners along the value chain. As a result, the private sector faces ambiguities concerning ownership, liability and carbon-revenue accrual. Navigating these challenges requires clarification of rules at the international level (including regarding national greenhouse gas (GHG) inventories). It also requires consideration of technical and institutional aspects, such as needing to ensure that project owners have control over the durability of storage. Lacking clarity regarding project ownership, liability or contractual assurance can become problematic in case of leakage or when regulations and carbon market rules evolve. Identifying key stakeholders and creating clear arrangements are vital and need to draw from best practices and existing guidelines to maximise compatibility across multiple storage hubs and clusters of emission sources.

2.2 Blueprint focus

The focus of this blueprint is generating carbon credits from a Swiss waste-to-energy (WtE) plant with carbon capture, transport and storage abroad under the VCM standard VCS (Figure 2). Section 3 provides further details.

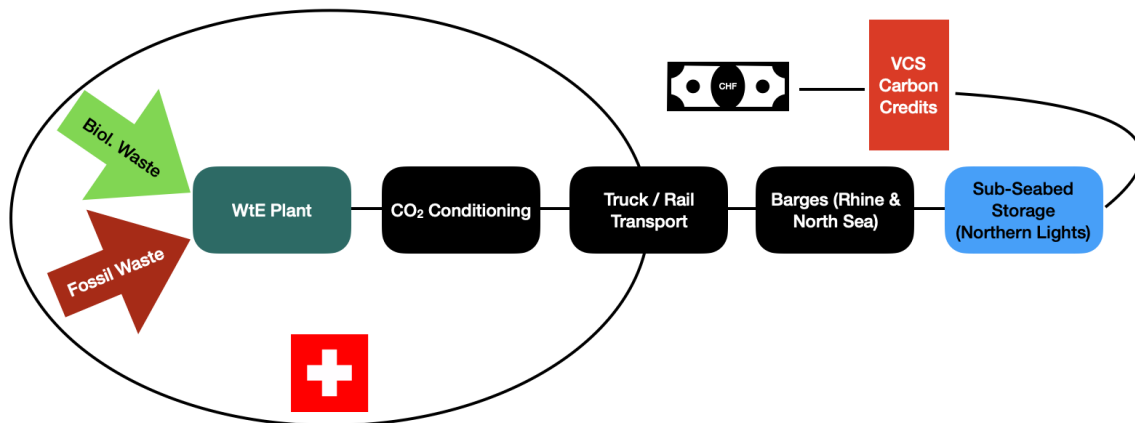


Figure 2: The value chain and monetisation option detailed in this blueprint

(Source: Authors, 2023)

2.3 Objective

The goal of this blueprint is to answer:

‘How can Swiss WtE-CCUS project developers generate revenue based on the mitigation results of their activities in carbon markets and beyond?’

The VCM is the starting point as this is what the underlying ensemble of methodologies has been designed for. As existing standards do not yet provide robust methodologies for certifying complex CCUS activities, the blueprints build on a state-of-the-art carbon accounting infrastructure currently under development by the CCS+ Initiative for the VCS. The CCS+ methodologies provide a high-quality standard for the responsible adoption of CCUS activities (CCS+ Initiative, 2023). Using such a strict standard enables project developers to fulfil the transparency and environmental integrity requirements of voluntary or compliance standards that may emerge in the future across jurisdictions around the world. This blueprint shows the process to generate and sell carbon credits under the VCM, including guidance to define the project design document (PDD), which builds on methodologies’ robust technical considerations. In a second step, the blueprint also shows how a largely identical approach may allow the use of methodologies for tracking emission reductions and CO₂-removal results beyond the use for selling voluntary credits in other carbon-crediting and results-based incentive systems. It shows the opportunities, challenges and pitfalls of each of these avenues to carbon revenue.

While the blueprint explains the approach under the VCM, it addresses how alternative paths to monetisation deviate from it. This includes authorisation of VCM credits for transfers under the Paris Agreement Article 6.2, generation of credits under the Swiss compensation instrument, generation of credits under the UN A6.4M and implications of emissions trading systems (ETS)(see Figure 3).

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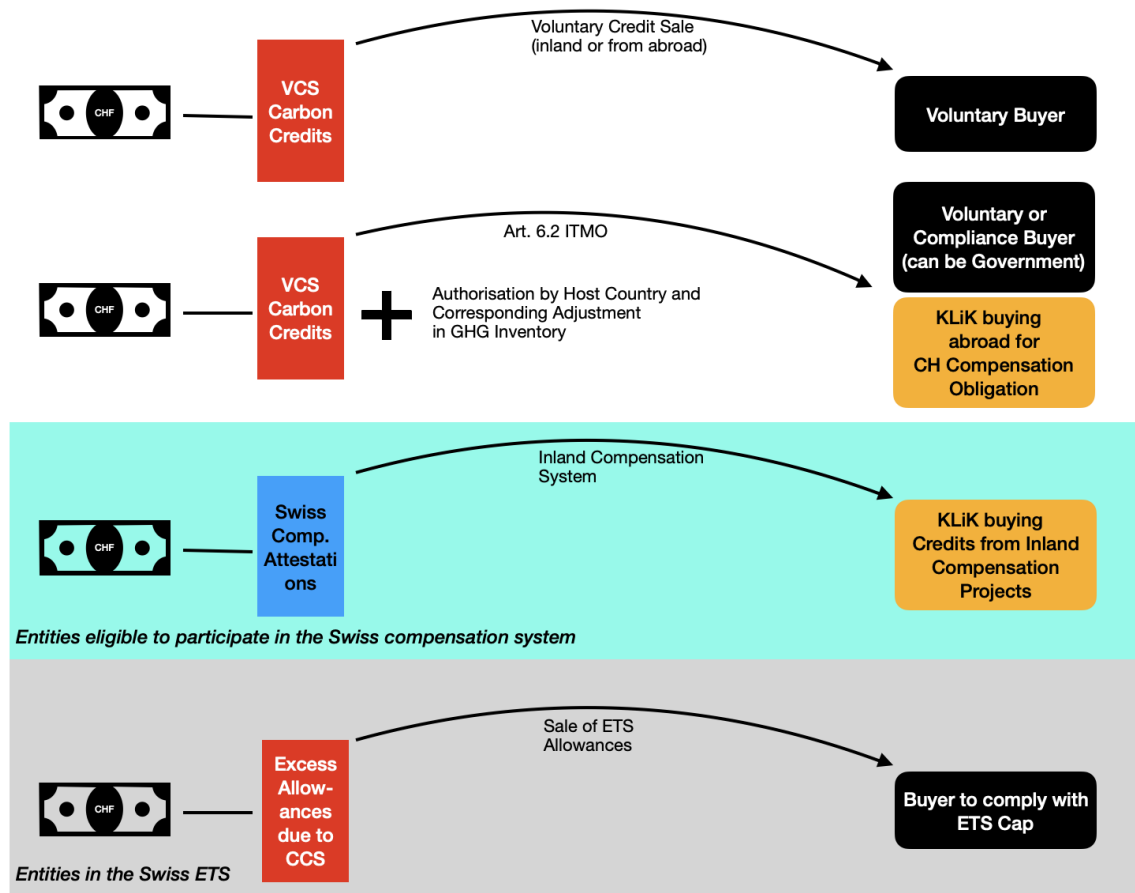


Figure 3: Overview of the four possible avenues of monetising mitigation results examined in the four blueprints

(Source: Authors, 2023)

2.4 Materials and methods

This blueprint draws primarily on the applicable baseline, and monitoring, reporting and verification (MRV) methodology, modules and tools. These were developed by Perspectives and South Pole with input from stakeholders in CCS+ and DemoUpCARMA. Secondly, blueprints and methodologies are informed by provisions in the contexts of GHG inventories, EU storage rules and EU carbon certification considerations, as well as the UNFCCC Article 6. Pertinent information on these matters is incorporated in condensed form to offer a cohesive guide to approaching international cooperation on transboundary CCUS value chains designed for maximum compatibility with these policy contexts, for the case of a waste incineration plant in Switzerland connecting through various means of transport and via a third-party country to a storage site in Norway (or other storage sites in the EEA).

3. Description of the value-chain use case

CCUS projects involve the capture of CO₂ from a point source or directly from the atmosphere. The captured CO₂ is typically compressed and transported by pipeline, ship, rail or truck to be injected into deep geological formations (e.g. deep saline aquifers, depleted oil and gas reservoirs, or reactive rock formations). Alternatively, CO₂ can be stored in the long term in building materials.

3.1 Description of the scope of activities

The value-chain case example outlined by this blueprint includes the collaboration between an entity (domiciled) in Switzerland capturing CO₂ at a municipal waste incineration facility, transport of CO₂ through Switzerland, Germany, Denmark and the North Sea for storage at the Northern Lights site (though the rules would be likewise for equivalent storage sites elsewhere in the EEA). The example includes capture at a (municipal) waste incineration plant followed by transport of CO₂ via trucks, rail, ships and barges from the capture site in Switzerland to Norway for subsurface supercritical CO₂ storage by the private consortium project 'Northern Lights'. The example could also be applied to other countries in the EEA with similar transport and storage conditions.

A key aspect of developing and describing a carbon project (as shown in Section 4) is determining its boundaries in time and space. Table 1 outlines what this could look like in the case examined here.

Table 1: Project boundary

Geographical boundary	Refers to the location of the project activities.	Switzerland, France/Germany (Rhein), international waters, Norway; WtE plant operation, conditioning, transport (trucks, barges), offshore storage site.
Temporal boundary	Refers to the timeframe during which the project activities occur and impact GHG emissions.	VCS crediting period for projects involving geological carbon storage is set at a maximum of seven years, renewable up to five times, with a total project crediting period not to exceed 42 years.
GHG sources	All relevant sources of GHG emissions are identified and included within these boundaries.	WtE plant, conditioning leakage, transport leakage, energy required for conditioning, transport, and storage, storage site leakage.
Secondary effects²	The project boundary also considers secondary effects related to the project.	Secondary effects could include emissions associated with a relative increase in heating and power from other sources (due to the reduction in output from the WtE plant).

² Most methodologies foresee a materiality threshold that allows cutting off secondary effects of irrelevant size to avoid unnecessary complexity.

(Source: Authors, 2023)

Municipal solid waste plants are CO₂ point-source emitters of up to 4 MtCO₂ per annum with prospects of increases over time, depending on population growth and capacity expansions. Many plants provide district heating and electricity based on the waste disposal service. There is thus a trade-off to consider as higher capture rates cut drastically into heat production or even into electricity production (if heat pumps are required to generate sufficient heat for the operation of the capture module). The project could, however, be designed to optimise for different values, notably in regards to the maximum capture rate, which would change those emissions values. For example, it could be designed to utilise all available heat (without additional heat input to the capture process), which would achieve a maximum capture rate of 58% – or the capture rate could be increased to 99%, which would cut the electric power output in half due to the need for heating with heat pumps (Otgonbayar et al., 2023).

A CCUS value chain as envisaged with storage in Norway is estimated to incur total costs exceeding 400CHF/tCO₂ in the medium term (once there are dedicated barges that allow transport through the North Sea directly to the Northern Lights storage site) (Figure 4). The cost may evolve as this blueprint's value-chain case may benefit from cost reductions as later plants follow in the footsteps of the first-of-its-kind plant (Kehrichtverbrennungsanlage (KVA) Linth).

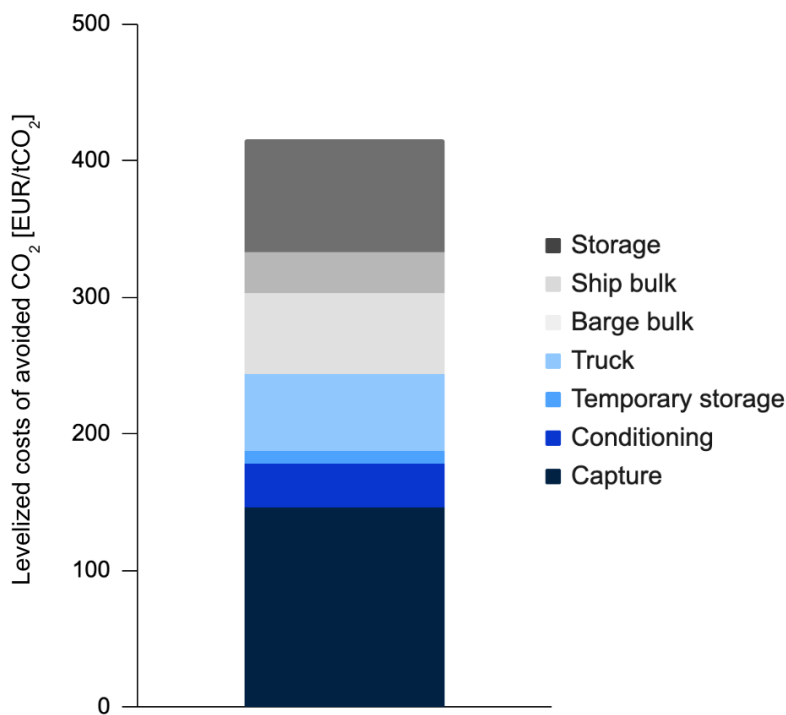


Figure 4: Estimates of the respective contribution to total cost based on the similar example of KVA Lindth

(Source: Oeuvray et al., 2022)

Such a value chain is expected to generate significant emissions at various stages, amounting to a total of nearly 0.3tCO₂ for each ton of CO₂ stored. The majority of those emissions stem from

transport and a smaller amount (ca. 0.1t) is related to the capture process (residual emissions and energy penalty; see Figure 5 showing a comparison of CO₂ emissions per ton of CO₂ stored from three possible Swiss CCUS installations).

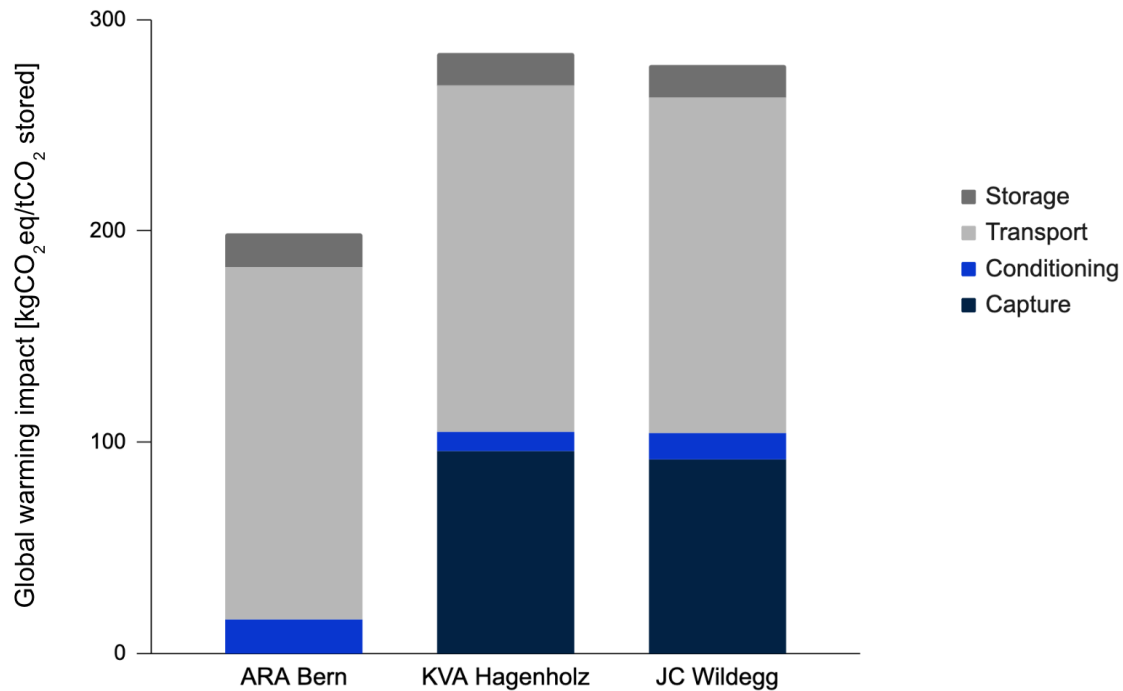


Figure 5: Emissions occurring throughout the value chain for each tCO₂ stored

(Source: Oeuvray et al., 2022)

3.2 Technical feasibility and barriers

Implementing WtE CCUS across national borders presents a unique set of challenges. While the first plant is being conceptualised in accordance with the waste-sector agreement³, this international endeavour does not appear to face any glaring, insurmountable technical obstacles. However, this does not mean the path is clear; numerous smaller operational challenges are anticipated. These minor hitches, though not individually critical, can cumulatively complicate the smooth implementation and management of cross-border WtE CCUS projects, necessitating early planning for the specific mitigation (crediting) results envisaged and flexibility in adapting to numerous technical and non-technical requirements.

³ The Swiss government and the Swiss Association of Waste-to-Energy Plant Operators, VBSA, signed a sector agreement in March 2022 (UVEK, 2022) This sector agreement follows up on the emission reduction goals set in 2014, which expired in 2021. It obligates operators of municipal waste incineration plants to construct at least one capturing facility by 2030 with the capacity to capture a minimum of 100,000 tCO₂ per year. The incentive for entering such an agreement was the continued exemption from being subject to the Swiss ETS

3.3 Relevant information on the value chain for crediting and monetisation

When embarking on a WtE-CCUS carbon project, several pivotal considerations come to the fore. First and foremost is the issue surrounding transboundary transport of CO₂ for storage. Specifically, there is an urgent need to pinpoint where the mitigation result occurs, especially in cases like Switzerland and Norway, as discussed in Section 9.2. Furthermore, the uniqueness of a first-of-its-kind installation presents the possibility of it being automatically deemed additional. Notably, subsurface storage of CO₂ is governed by the EU CCS Directive.

There are also potential implications should the waste sector get incorporated into the Swiss ETS later this decade or by 2030. The immediate concern is that crediting of any kind may become unviable if additionality cannot be showcased. Certainly, waste sector entities covered by the ETS would lose the privilege of generating credits in the domestic compensation instrument and it could also challenge voluntary carbon market crediting including for purchases by the Swiss government (seeking to meet its net-zero target). Whether any single WtE-CCUS project would constitute a compliance project under the extended sector agreement would also affect its additionality. The additionality of subsequent plants will have to be gauged in light of potential future agreements and their economic and other barriers.

Similarly, the baseline scenario (currently, presumably 'no intervention') may have to change in case the waste sector is subject to obligations flowing from the sector agreement. A crucial piece of data required will be the proportion of CO₂ stemming from sustainable versus non-sustainable sources (i.e. 'sustainable' biomass wastes versus non-sustainable biomass and fossil wastes). This distinction is vital for differentiating between emission reductions and removals concerning the baseline, the project and potential leakage emissions. To clarify, both fossil carbon and non-sustainable biogenic carbon point towards CO₂ reduction, while only sustainable biogenic carbon translates to CO₂ removal.

4. How to generate and monetise credits under the VCM

The VCM has grown in recent years and offers a meaningful source of revenue for climate mitigation results. The VCM involves the sale of carbon credits, which can be bought for voluntary offsetting, voluntary (non-offsetting) mitigation contributions or in some cases also for offsetting obligations (if additional requirements are met). Credits are issued through a formal process by standards such as the VCS and can be traded either directly or through intermediaries. Though often used to make carbon neutrality claims, they increasingly serve more broadly as a means to track mitigation results in a consistent and verifiable manner.

The process of generating carbon credits essentially serves to transparently demonstrate that the conditions for integrity are met by the proposed activity. The integrity of carbon credits requires transparently meeting the seven factors shown in Figure 6.

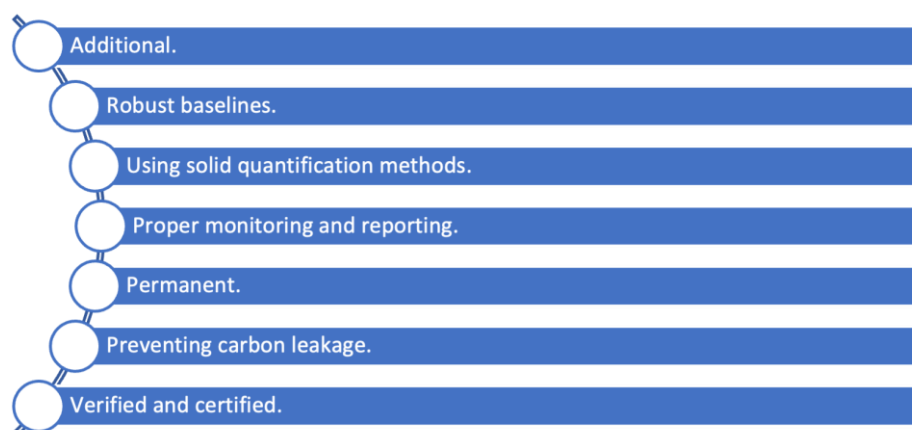


Figure 6: Criteria relevant to the integrity of carbon credits – to be demonstrated transparently by the standard

(Source: Authors, 2023)

Methodologies are vital for quantifying greenhouse gas benefits, generating credits and monetising them. These methodologies are regularly updated for accuracy and relevance. For this, specific methodologies have been developed under a voluntary carbon market standard – in our case, under the Verified Carbon Standard (VCS), the 'Methodology for Carbon Capture and Storage' is applicable along with the:

- Module for CO₂ Capture from Biogenic Sources,
- Consolidated Module for CO₂ Transport,
- Module for CO₂ Storage in Saline Aquifers.

In addition to the methodology and its modules, there are two relevant tools (see Figure 7):

- *Tool for differentiating reductions and removals in CCUS projects:* It is used to differentiate emissions reductions and removals. In the case of this blueprint, where a mixed feedstock

(fossil and biogenic) is used (WtE) the capture module from biogenic sources in combination with this tool, allow to account for both CO₂ stream.

- *Tool for Baseline Quantification and Allocation of Project Emissions in Projects with VCS and non-VCS-CO₂ flows in Carbon Capture and Storage Projects:* In case an activity is subject to a compliance market system and would like to also benefit from voluntary carbon market revenue this tool is needed to differentiate between the CO₂ from VCS and non-VCS project activities, as CO₂ leaving the project boundary (i.e. non-VCS CO₂) must be quantified and excluded from the project's emission reductions or removal results that may be credited in the VCS.

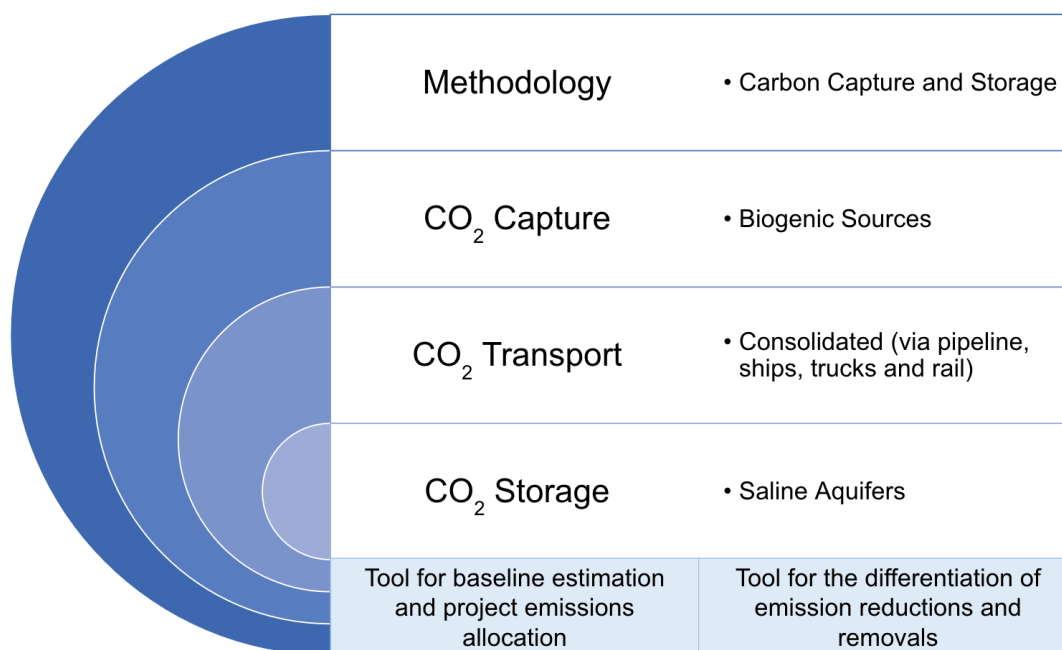


Figure 7: CCUS Methodology, its modules for capture transport and storage and accompanying tools applicable in this blueprint.

Source: Authors, 2023

Examining early the information required – by the methodology and tools – from the prospective project and the various partners involved, will make it easier to prepare the necessary institutional and contractual arrangements for partners along the value chain as outlined in the following step 0.

Step 0: Preparations for a transboundary CCUS value chain

The complexity of CCUS value chains requires a number of measures even before formally starting the carbon project development under a specific standard. This notably includes figuring out the most suitable institutional arrangements along the value chain, including signing agreements to meet VCS requirements. Important requirements to consider at the outset (for all projects involving

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geological storage of CO₂) are outlined in the ‘Geologic Carbon Storage (GCS) Requirements’ (Verra, 2023b). The GCS is the key tool for ensuring inter alia that the entity receiving credits is also held responsible should reversal occur (upon leakage from the storage site). It offers an important basis also to consider the question of who is going to be the project proponent; it can be preferable that the storage site operator is also the project proponent, or that they are tied contractually to ensure the durability of storage and dealing with reversals.

Alternative modes of collaboration should also be considered. For example, instead of choosing one of the partners in the value chain to act as the project proponent and project developer, partners could form a legal entity for the purpose of developing the carbon project. A third model is that an outsider–professional project developer acts as the project developer on behalf of the value-chain partners, which offers the advantage that in some cases such a project developer takes on the financial cost and risk of the project development itself.

Another important tool that may be considered at the outset is the Non-Permanence Risk Tool (NPRT) (Verra, 2023a), which offers an evaluation of reversal risk. Early consideration of reversal risk may help structure contractual arrangements for dealing with the consequences of reversals among value-chain partners should it occur later on (e.g. to avoid unduly placing the financial burden on certain partners or failing to ensure appropriate incentives for the partner responsible for storage).

Furthermore, decisions need to be taken at the outset regarding the envisaged accrual and use of credits inter alia to prevent double-counting issues. This includes whether the results are to accrue under the domestic Swiss compensation system as a so-called ‘Innlandszertifikat’, or whether – if the results accrue abroad – an international transfer (back to Switzerland) is envisaged as an Article 6.2 internationally transferred mitigation outcome (ITMO) (requiring corresponding adjustment as described in Section 4.2). Similarly, it may be worth considering whether the share of removals may in the results be marketed separately (targeting buyers who are willing to pay a premium for innovative removal credits) and for this, a clear distinction between both types of results is required (using the corresponding tool).

For any ambiguities that imply decisions by governments (potentially in bilateral state contracts), the resolution should be proactively sought from the respective authorities. This concerns: a) cases where there is ambiguity as to where results occur, b) whether consequently an Article 6.2 transaction is envisaged and c) whether the activity may be eligible for the Swiss domestic compensation instrument as either an inland-compensation project or as a foreign-compensation project. To undertake the first transboundary CCUS carbon credit project will require time to develop a shared understanding as a basis for formal collaboration contracts. This includes translating key concepts from contexts such as national GHG accounting, carbon markets, infrastructure planning, local waste incineration and storage of CO₂. A common understanding of the technical, legal and contractual requirements and associated responsibilities is needed to then translate into appropriate contractual arrangements as the basis for collaboration.

The following steps 1–6 are part of the so-called ‘carbon project cycle’ exemplified hereafter for the VCS.

Step 1: Activity design

The process, as demonstrated in the example of the VCS, is very similar in most standards and is often referred to as the ‘carbon project cycle’. The key phases are shown in Figure 8. The process

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for carbon credit issuance typically begins with a PDD submission by the activity developer. This document outlines the activity, baseline and monitoring methodology. An independent third party validates the activity before registration. Once operational, the developer monitors and reports emissions reductions as per the PDD. The outcomes are then independently verified for carbon credit issuance.



Figure 8: The carbon project cycle from idea to issuance of credits

(Source: Authors, 2023)

This is the most work-intensive phase for the project proponent. It culminates in the preparation of a Project Design Document (PDD), which captures all relevant information as required by the methodology (including for additionality demonstration, baseline identification and the monitoring plan). PDDs serve a key role up to validation as they demonstrate a proposed project's compliance with the conditions for integer carbon projects (see Figure 6). The PDD's core elements are shown in Figure 9.

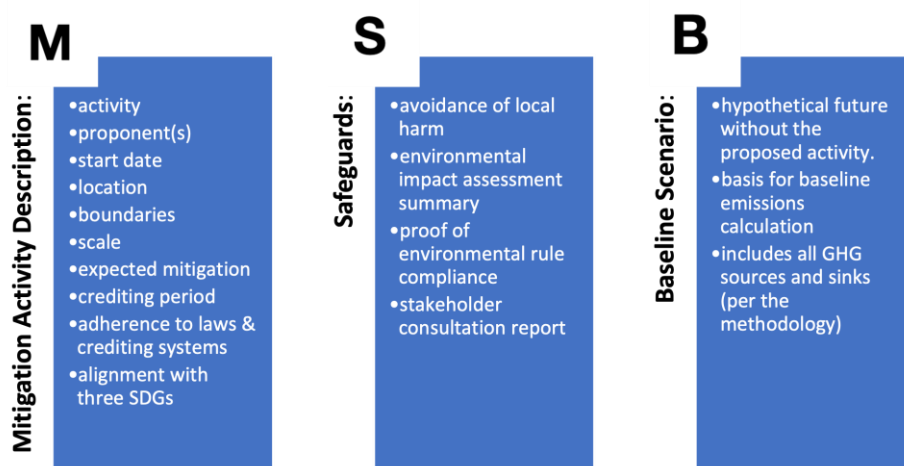


Figure 9: The core elements of a project design document (PDD)

(Source: Authors, 2023)

A central element in developing the PDD is the definition of the project boundaries, which is particularly challenging in the case of CCUS activities; while in the simplest cases, the project comprises of a single capture, transport and storage facility, it is also possible that multiple capture facilities are included through a shared storage facility, or vice-versa that CO₂ captured from a single

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site is stored at multiple sites. For all these processes, the project boundary includes electricity, fuel, and material inputs as well as their associated emissions – including venting and fugitives.

Another key piece is the setting of the baseline, which in the case of adding carbon capture (for storage) to an existing WtE plant essentially assumes a continuation of CO₂ emissions corresponding to the mass input of waste (i.e. absence of CO₂ capture from the facility). The baseline emissions can be determined by the amount of CO₂ injected at storage sites. To allow separately selling removal and emissions reductions credits from WtE with mixed fossil and biological inputs, the *Tool for differentiating reductions and removals in CCUS projects* sets out the steps for a differentiated baseline (which is a precondition for differentiating results).

The PDD will also need to demonstrate additionality – to show that without carbon revenue from credit sales, CCUS would not be done. This is crucial for the integrity of carbon markets and ensuring efficient mitigation. For CCUS on a WtE plant, its proof needs to be provided following the guidance of the CCUS methodology in three steps: 1) Regulatory Surplus, 2) Implementation Barrier and 3) Common Practice. This means that 1) the project is delivering mitigation beyond regulatory requirements, 2) that a financial barrier is in place and 3) that the activity is not (yet) common practice. Projects that pass all three of these steps are considered additional. It is possible that WtE CCUS activities might – partly – be allowed to follow a simplified approach, but this remains to be seen: Demonstration of the regulatory surplus will be required in any case, but it is possible that WtE will be considered automatically financially additional in the future.

In the PDD, the proponent will also need to present the monitoring plan. This plan anticipates the monitoring activities that will be required during the monitoring period. It indicates the physical equipment to be used (e.g. meters), and the various partners' responsibilities and processes for collecting, processing and reporting data, as required by the methodology. It defines the parameters that need to be measured, their accuracy and the measurement frequency.

Step 2: Validation

Upon submission of a PDD by the project proponent to the standard body, the validation process starts. It involves a third-party validation/verification body (VVB) – approved by the carbon credit standard – which independently checks if the proposed project meets the standard's requirements. The first step of validation is a public review for about a month, followed by desk evaluation and then a site visit by the VVB. Based on these inputs, the VVB examines the accuracy of claims in the PDD, and either recommends the project for registration or suggests changes before it can be registered.

Step 3: Registration

Upon validation, the carbon standard performs a completeness check and registers the project in its registry. This enables the project owner to generate carbon credits for an initial period, called the crediting period. The length of the crediting period is set by the standard and can vary for different project types. For projects including geological carbon storage, the VCS has set the project crediting period to seven years, renewable up to five times, with a total project crediting period not to exceed 42 years to consider the longer lifespan of such projects.

Step 4: Monitoring and reporting

Upon registration and the start of activities, the MRV of results starts. A monitoring report is prepared following the data and information requirements set out in the latest VCS requirements

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for geological carbon storage and the respective methodology and modules. The storage module requires project proponents that monitoring plans must support the permanent storage of injected CO₂ by ensuring containment of the plume over time. The plan must further describe techniques, define the detection threshold and determine the expected mean time to detect a loss of containment, among other parameters. If a loss of containment occurs, the procedures outlined in the VCS Program (Verra, 2023c), the GCS requirements and the GCS NPRT shall apply.

Step 5: Verification of results

The report is verified by a VVB and the project proponent can then file a credit issuance request to the carbon standard.

Step 6: Issuance of credits

If everything is in order, credits will be issued in the registry and transferred to the proponent's account. Active credits can then be sold to gain revenue.

Step 7: Sale of credits

There are two key types of buyers: intermediaries/market aggregators, and end users. The latter include individuals, businesses and governments, but for project proponents with a small portfolio, they will be difficult to reach. Intermediaries include brokers, traders and exchanges (e.g. Carbon Trade Exchange (CTX), the CME Group and Xpansiv), which tend to charge a fee ranging from 5% to 20%. The sale can happen either before credit issuance (via an Emission Reduction Purchase Agreement (ERPA)) or after issuance. ERPAs under the VCS follow a template (IETA, 2023), which establishes roles, rights and responsibilities regarding project risks besides price, amount and credit delivery timeline. Another option for project initiators is partnering with activity development partners, who accompany the project from its inception to issuance and in some cases front the associated expenses to in turn be remunerated with a portion of credits generated later.

Removal-based credits are expected to fetch a higher price than those representing emission reductions, especially those that can clearly demonstrate durable storage.

4.1 CCUS methodology beyond CCS+ Initiative

Unlike other alternatives, the CCS+ carbon accounting infrastructure offers a unique modular 'plug-and-play' system approach to properly incorporate a wide set of possible project configurations. The aim is to include the majority of the current CCUS activities, and by addressing each technology type separately, future solutions can be effectively integrated into the infrastructure.

Today technology and industry players in the CCUS space offer a wide range of carbon capture, transport, utilisation and/or storage solutions. All these solutions need to be addressed and accounted for in their unique way. Methodologies are usually focused on specific technologies or define a set of eligible activities. This potentially leads to mitigation activities from one emitting sector not being eligible under the same accounting methodology due to different use of technologies or project activities. This is where the CCS+ initiative accounting structure would come into play.

BP2a – International CCUS collaboration

In addition to the methodologies developed by the CCS+ Initiative under the VCS, various other carbon standards are actively working on the development of robust accounting methodologies to tackle the diverse and complex topic of CCUS. This section offers an overview of methodologies available or under development, specifically concentrating on carbon standards endorsed by the International Carbon Reduction and Offset Alliance (ICROA)⁴.

In this blueprint, the project scope deals with the capturing of fossil and biogenic CO₂ from a Swiss waste-to-energy (WtE) plant with carbon capture, transport and storage abroad. Depending on the specific technologies used in the project design, these activities could potentially be covered by methodologies drafted by the Global Carbon Council (GCC) and published by Puro.earth (Puro).

Global Carbon Council (GCC)

At the time of writing, the GCC has published a draft methodology for project activities for the capture, transport and geological storage of CO₂ (GCC, 2023). In this draft, any activities capturing fossil or biogenic CO₂ sources from high-purity industrial sources, combustion sources or DAC are eligible. All means of transport of CO₂ by rail, road or ship are covered. CO₂ storage is eligible in saline aquifers and depleted oil and gas wells. For CO₂ emissions from fossil and biogenic sources, as in this blueprint example from a waste-to-energy facility, a differentiating tool between reductions and removals is in development. Similar to the methodology infrastructure developed by the CCS+ Initiative, GCC addresses a range of project activities regarding capturing, transport and storage, making it attractive for project developers who have multiple options for their value chain.

Puro.earth (Puro)

Puro is focussed solely on removals, technological/industrial or nature-based. The geologically stored carbon methodology (Puro.earth, 2021) covers activities from the capturing, transporting and storing of CO₂ geologically. Eligible source of CO₂ is limited to biogenic sources or the biogenic parts from mixed emission sources as in the example of this blueprint. CO₂ can be transported to the storage site by all means of transport. Geological storage includes storage in saline aquifers, depleted oil and gas fields and activities related to Enhanced Oil Recovery 'EOR' with the condition to store more CO₂ than what is contained in the extracted oil due to these activities, so-called 'EOR+'. While most of the CCUS methodologies are still under development, Puro's methodology is already available and ready to be used in the VCM.

Generally speaking, all standards, which are discussed in this blueprint, follow the same goal of developing rules, requirements and procedures for the design, development, monitoring and reporting of carbon projects which then results in an emission reduction or removal. Yet, when examining individual technology groups and solutions in isolation, rather than considering the entire value chain as a whole, the CCS+ initiative can craft a more robust carbon accounting mechanism for diverse project value chains.

⁴ ICROA collaborates with various stakeholders in the voluntary carbon market, including project developers, carbon standards, and businesses seeking to offset their carbon emissions, promoting high standards and best practices in the voluntary carbon market. It ensures measurable, permanent, additional and independently verified emissions reductions.

4.2 Use of VCM credits or dedicated crediting for use under Article 6.2

Under the Paris Agreement, countries can cooperate to achieve their NDCs based on the authorised transfers of 'mitigation outcomes' (which then become ITMOs). ITMOs can also be used towards obligations on international aviation under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

Authorisation as a precondition for ITMO transfer requires that the party from which the credits originate apply a so-called 'corresponding adjustment' (CA) to its GHG inventory. It is important to highlight that CAs do not alter the national GHG inventory but rather serve as adjustments to the emission balance, reflecting the emissions source under NDC targets. When a country uses the ITMO to achieve NDC targets, the buyer country also applies CA in its inventory. In most cases, ITMO transfer will rely on crediting via an established VCM standard (notably including the VCS), but countries can in principle also develop their own crediting systems if both buyer and seller countries agree on the requirements. Credits authorised as ITMOs have a broader demand base, including governments, airlines and voluntary buyers, and are likely to fetch a higher price. Credits without CA are increasingly seen as unfit for compensation and carbon neutrality claims, meaning that over time voluntary buyers will be willing to pay a premium once CA and ITMO transfers are operational at national and UN levels in one to two years.

Switzerland and other countries are already engaging in purchasing contracts with entities abroad – and with their respective governments – to determine quantities, conditions and responsibilities for carbon credit generation and ITMO transactions.

5. Swiss compensation scheme

The Swiss compliance scheme is driven by the mandate outlined in the country's CO₂ Act (Federal Assembly of the Swiss Confederation, 2011), which requires fossil-fuel importers to offset a specific portion of their emissions. To meet this legal obligation, the KliK Foundation acts as an intermediary, connecting fossil-fuel importers with emission-reduction projects⁵ that generate carbon credits. These carbon credits from the approved projects are sold to fossil-fuel importers to offset their carbon emissions. The compensation scheme distinguishes between domestic projects within Switzerland and those undertaken abroad. The compensation obligation is defined as a specific percentage of the overall emissions produced by the imported fuels, which have to be offset partially in Switzerland and internationally. For a more in-depth exploration of the Swiss domestic compensation scheme and further details on additional CCUS activity support funded by unused funds from KliK's predecessor, the Climate Cent ('Klimarappen') Foundation, please refer to a separate document developed under the DemoUpCARMA project (South Pole, 2023).

This chapter is dedicated to providing prospective CCUS project developers in the value chain outlined in this blueprint with insights into procedures for establishing a CO₂ compensation project under the Swiss compliance scheme. The chapter describes aspects of project development, which share similarities with developments in the VCM. Nevertheless, within the compliance scheme, several processes and structures are different (e.g. relevant documents around the registration of a climate project). Under the VCM, a clear distinction is drawn between a methodology and a project development. While a methodology defines standardised rules for executing, monitoring and verifying emission reductions, ensuring consistency across projects, the PDD describes unique project-specifics that apply a methodology, detailing project specifics and serving as evidence for each individual carbon offset project. In the Swiss compensation market, these essential documents are combined into a joint project description and a monitoring plan. Nevertheless, they all include critical elements such as additionality, baseline definition, MRV processes, system boundaries, leakage and conservative CO₂ reduction quantifications. Unlike the VCM, where project proponents can potentially apply an existing standalone methodology to their project, Swiss compensation mechanisms require the development of all relevant documents for each project.

Another notable feature of the Swiss compliance scheme is the compensation obligation imposed on the KliK Foundation. Securing Swiss 'attestations,' hereafter referred to as carbon credits, is subject to negotiations with project developers. It is essential to recognise that buyers in the VCM may also become potential purchasers of these credits. Typically, project proponents engage in ongoing discussions with KliK throughout the registration process with FOEN. A process, detailed later in this chapter, such as the option to have a 'project outline' document evaluated by a validator and verifier (VV), provides an initial estimate of certificate quantities and the project's likelihood of acceptance and registration. Early discussions will be relevant for financial assessments during project development.

The following chapters provide an overview of the registration process for the chosen cross-border CCUS project value chain, while also highlighting requirements and general principles. For an in-depth description, please refer to the document provided by FOEN (FOEN, 2022). The provided

⁵ The Swiss compensation scheme allows the development of single projects or programs that group several activities with common purposes. For simplicity, this document only refers to projects.

overview and information on the Swiss compensation scheme are extracted from the same document.

5.1 Procedure towards carbon credits

In the Swiss compliance market, the procedure for generating carbon credits closely mirrors the carbon project cycle previously outlined for the VCM, as depicted in Figure 8. Figure 10 provides a visual representation of the application process (Steps 1 to 3), and the ongoing monitoring, verification and transfer of carbon credits (Steps 4 to 6). In addition to these six steps, the figure emphasises the various documents that require authorisation, validation or verification by the involved stakeholders. In our project example, these stakeholders include FOEN in Switzerland, a VV (a third-party validator, similar to a VVB in the VCM) in Switzerland as the host country and all partner countries within the CCUS value chain.

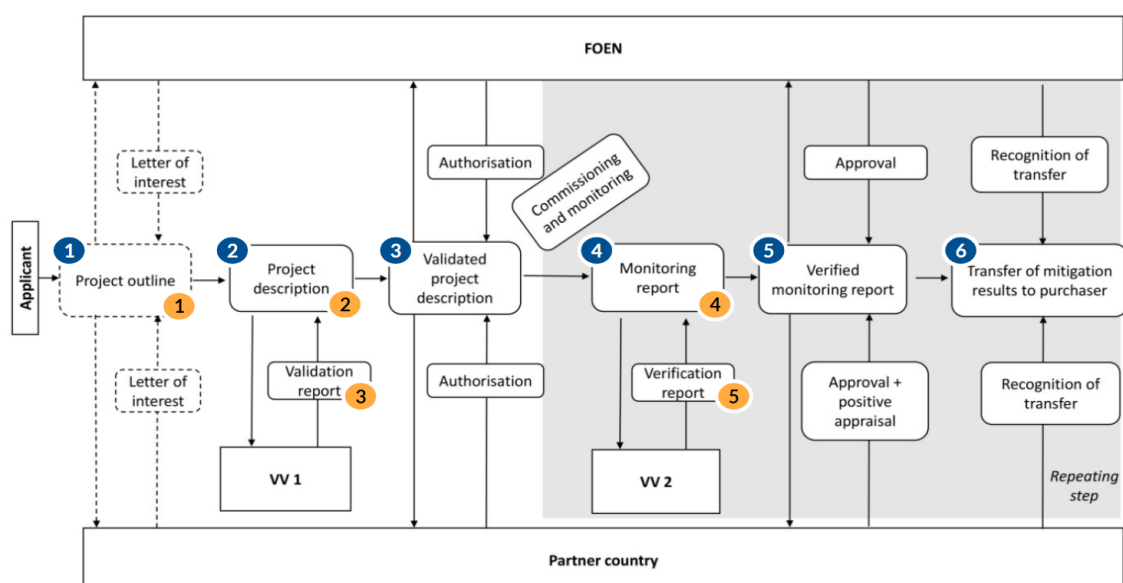


Figure 10: Swiss compensation scheme procedure (blue circles indicate carbon project cycle steps; orange circles indicate relevant project development documents⁶ necessary for application and ongoing monitoring, verification and credit issuing cycles)

(Source: adapted from FOEN, 2022)

Step 1: Project outline (optional)

In the first optional project outline, the developer can submit a project outline document to the FOEN and the partner country. This document serves as a preliminary assessment and provides a first eligibility judgment. Critical issues include additionality, differentiation from other climate policy instruments and preliminary calculation of expected emission reductions.

⁶ Procedures and templates for project development can be found on FOEN's website (FOEN, 2023b).

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Step 2: Project description and validation

A detailed project description includes the following information: A detailed project description, an economic feasibility analysis, reference scenario development, differentiation from other climate policy instruments, a calculation method for determining emission reductions, a monitoring plan, and the validation report. The validation report is the revision of the project description by a FOEN-approved VV.

Step 3: Authorisation

After the VV approves the project description in a validation report, the project developer receives authorization from FOEN and the respective partner countries involved along the project value chain, the project is eligible to commence the annual, ongoing Monitoring, Reporting, and Verification (MRV) process.

Step 4: Monitoring

The project description defines the start date for monitoring emissions and the method for demonstrating emission reductions. Typically, monitoring begins when the project becomes operational. The monitoring report demonstrates the emission reduction according to the monitoring plan outlined in the project description for each year. The monitoring report has to be verified by the VV.

Step 5: Approval by FOEN and partner countries

The verified monitoring report must be approved by the FOEN and partner countries.

Step 6: Transfer of mitigation results (carbon credits)

Carbon credits are transferred to the KLIK Foundation.

5.2 Eligibility of the proposed CCUS project value chain

As of the revision to the CO₂ Ordinance in June 2022 (Federal Assembly of the Swiss Confederation, 2012), CCUS projects involving long-term storage in biological or geological formations, or non-organic building materials (e.g. concrete) have become eligible for the generation of carbon credits within the Swiss domestic compensation scheme.

All project developers need to set up a project description which will assess the eligibility of the proposed project in detail (Step 2 of the carbon project cycle). Below, several issues, relevant to the specific project value chain described in this blueprint are discussed.

Compliance with applicable legal provisions, differentiation from other climate policy instruments and avoidance of double-counting

Similar to projects in the VCM, this blueprint's project case must demonstrate compliance with other relevant legal provisions, and differentiation from other climate policy instruments and must avoid double counting. For instance, if future regulations were to mandate CO₂ capture from WtE plants, the generation of carbon credits within the Swiss compliance market would not be possible.

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Notably, all WtE plants in Switzerland have entered into a waste-sector agreement to exempt themselves from inclusion in the Emission Trading System (ETS) (UVEK, 2022).

As previously outlined in Section 3.3 a potential issue arises, necessitating clarification regarding whether WtE plant CO₂ capture projects align with the compliance requirement specified in the agreement—covering the capture, transport and utilisation or storage of 100,000 tCO₂ annually by 2030. Any CO₂ captured before 2030 or above that threshold, from 2030 onward, should technically be considered compliant with the relevant legal provisions. In this scenario, addressing the intersection of these two policy mechanisms is important to provide clarity on the eligibility of WtE plant CO₂ capture for the Swiss compensation scheme.

To demonstrate compliance with the legal provisions of countries in which project activities are taking place, bilateral climate agreements⁷ are a necessary precondition to carrying out projects in foreign countries under the Swiss compensation scheme. Currently, Switzerland has no such agreement with Norway and as of today, no cross-border projects are registered under the Swiss compensation scheme.

If the WtE sector agreement fails to achieve its objectives by the conclusion of 2030, with a potential extension until 2032, the entire sector faces inclusion in the Swiss ETS. This follows a similar pathway to the EU ETS, which is planning the incorporation of the waste incineration sector by 2028 (with a decision to be reached by 2026) (Council of the European Union, 2023). In Art. 5 para. 1 let c No 2 of the CO₂ Ordinance states that only emissions which are not covered by an emission trading system are eligible under the Swiss compensations scheme. This further adds uncertainty for CCUS project developers.

However, it's important to note that WtE plants process a diverse range of input waste materials, including those from fossil and biogenic sources. Given that biogenic CO₂ emissions are not encompassed by the sector agreement, the ETS (as of today), therefore suggesting, that such emissions would be eligible for a CCUS project under the scheme.

Permanence of carbon storage

Although the revision of the CO₂ Ordinance in June 2022 introduced long-term storage in biological and geological formations, in abroad projects, only geological carbon storage is accepted. Under the Swiss compensation scheme, stated in the CO₂ Ordinance (Art. 5 para. 2), projects need to demonstrate a CO₂ storage of at least 30 years, regardless of the project duration and including after completion of the project. These requirements can be met by all geological storage sites which are available today, most aiming for long geological-time scales (e.g. thousands of years). Here the question regarding the liability for the stored CO₂ arises, which should be answered in a bilateral agreement between the two countries. As mentioned in Section 4 (Step 0) documents from the Vera, namely the NPRT and the GCS requirements can be addressed to form an approach towards liability and storage requirements for CCUS projects.

⁷ A bilateral climate agreement that governs cooperation between two countries and establishes the legal framework for the implementation of climate mitigation activities, including a clear delimitation from partner countries nationally determined contribution (NDC). A list of bilateral agreements between Switzerland and foreign countries can be found on the FOEN website (FOEN, 2023a).

Demonstration of additionality

Additionality under the Swiss compensation scheme is demonstrated by providing evidence that the project would not be economically viable without the revenue from the carbon credits for the entire duration of the project^{8,9}.

This can be shown in one of the following ways:

- Simple cost analysis: As it would be the case for this project value chain, if a project has no other revenue streams apart from the sales of the carbon credits, a simple cost analysis is used. Demonstrating that the project is not profitable and less viable than the most likely alternative scenario.
- Investment comparison analysis or benchmark analysis: Key financial indicators such as NPV or IRR are compared between the project scenario and the alternative scenarios. An additional sensitivity analysis is done, to demonstrate the financial assessment is robust when assumptions are adjusted.

Projects might still be additional even though they are financially viable. In this case, a barrier analysis can demonstrate that the project is facing barriers such as technical difficulties or lack of trust among customers. In addition to the economic analysis described above, the project developer must show that the project is not common practice. The project activities described in this blueprint are far from being common practice, and as already mentioned, the only source of revenue would come from the sales of carbon credits.

Possible project duration

The Swiss compensation scheme, which obligates fuel importers to offset a portion of their emissions, was established based on the CO₂ Act. This legislative framework which enables the mechanism of the Swiss compensation scheme is in force until the end of 2030, with currently no follow-up legislation in place. Without subsequent legislation, fuel importers will no longer be bound to offset their emissions from 2031 onward. Consequently, project developers are left with no assurance that this revenue stream will continue to exist. The lack of certainty regarding the sale of carbon credits under the Swiss compliance scheme significantly diminishes the appeal of CCUS project development. A study conducted on a WtE plant 'KVA Linth' concluded that just a capture unit capable of capturing 100,000 tCO₂ per year would amount to ~25 million CHF without heat integration (~30 million CHF with heat integration) (Sustainability in Business Lab, 2021). Such projects entail substantial upfront investment costs and correspondingly extended amortisation periods, making them especially unattractive under these circumstances.

Determination of reference scenario

The reference scenario is the most likely alternative to the project scenario, generally being the most economically attractive scenario. A reference scenario is defined once at the beginning of a

⁸ It is essential to include all types and sources of revenue. These include development assistance from donors, other climate finance mechanisms, public funding or other non-refundable payments.

⁹ The economic feasibility analysis is based on UNFCCC's Methodological tool Tool for the demonstration and assessment of additionality (UNFCCC, 2012).

project. It is later compared to the measured project scenario to quantify the emission reductions and ultimately determine the amount of issued carbon credits.

For the period until the end of 2030, when the compensation obligation ends due to currently no follow-up legislation in place, which would describe a continuation of this obligation, a reference scenario would most likely follow the current situation of WtE plants continuing to emit CO₂ to the atmosphere. However, it would still be discussed, how the sector agreement would need to be accounted for during the reference scenario development.

Assuming, that all WtE plants will need to pay an equal amount towards the accomplishment of the agreement, creating a common baseline of contribution, it is still uncertain how additional CCUS projects would be treated under the Swiss compensation scheme. Further assuming a continuation of the compensation obligation after 2030, it is further unclear, how the sector agreement targets will be further expanded in the case of its successful implementation. In the case of WtE plants not meeting the target of the sector agreement, all WtE plants will be included in the ETS and would as previously mentioned not be eligible under the Swiss compensation scheme.

Monitoring plan, monitoring report, and quantification of emission reductions

The monitoring plan, a crucial component of the project description and initial authorization process, outlines all relevant parameters and data to be measured and reported throughout the project's lifecycle. It provides specific requirements for handling data and methods employed to calculate emission reductions. This comprehensive monitoring plan serves as a step-by-step guide, enabling project proponents, third-party validators, and the FOEN to precisely calculate and understand actual emission reductions in the yearly monitoring report. In cases where a parameter cannot be measured precisely, the estimate must be as accurate as possible, which requires the consultation of supporting scientific measures. Moreover, all emission reductions or parameter estimations must be made conservatively, following the principle of conservativeness, to prevent any overestimation. The yearly monitoring report, verified by the VV and the FOEN, calculates emission reductions for a given year by deducting project emissions and associated project leakage¹⁰ from the reference scenario.

¹⁰ Leakage refers to the change in emissions beyond the project activities that are not directly attributed to but influenced by the project. It can have either a negative impact, resulting in increased emissions, or a positive impact, leading to more emission reductions. Unless negligible, leakage emissions must be considered in the final emission reduction calculation. An example of leakage would be the necessity to offset the reduced energy output and increased use of fossil fuels due to the diversion of biomass from a waste incineration plant to a biogas plant.

6. Swiss emissions trading system

The Swiss ETS can incentivise the CCUS activities of the entities that are subject to it. Currently, the cement sector is subject to the ETS, while neither the municipal solid waste nor the liquid waste sectors are included. However, there are considerations that in the future (by 2026), the solid waste sector could be brought into the Swiss ETS following ongoing consideration of including waste in the EU ETS. The Swiss ETS is coupled with the EU ETS and adopts many of its changes.

The EU ETS and its regulations

The ETS Directive 2003/87/EC promotes CCS projects within the world's largest ETS. CCS helps decarbonise energy and industry under this system, with CO₂ that is captured, transported and stored recognised by the Directive. Emissions that are verified and permanently stored remove the need to surrender emission allowances. The addition of municipal waste incineration to the EU ETS by 2028 is being considered, and EU member states will need to track emissions from municipal waste incinerators from 2024 on to prepare for such integration. Section 2.2.4 delves into carbon crediting for CCS. The Monitoring and Reporting Regulation (MRR, 2018/2066) outlines EU ETS compliance, with guidelines for reporting CO₂ emissions from CCUS. The MRR also addresses CCU to some extent.

So, the ETS currently only represents a marginal consideration for waste-sector activities, although the possibility of inclusion should be taken into account when pursuing WtE-CCUS crediting. The future inclusion of the waste sector would have several important implications. It could undermine the additionality of some of the more economically viable activities under the VCS, which would result in halting the renewal of the crediting period. Some more costly projects could, however, still pass the additionality test even when the ETS results in additional incentives (essentially as long as the prices of allowances remain below the operating cost of CCUS).

In case of failing additionality determination due to ETS inclusion, the cost associated with operating the CCUS value chain would then fall on the plant operators, though they may also benefit from free allowances depending on how the inclusion takes place. The inclusion would ultimately open the possibility of overachieving the allocated cap (thanks to implemented CCUS) and, as a consequence, being in the position of selling excess allowances, thus again generating carbon revenue.

In the current form of the ETS, the inclusion of municipal waste incineration in the Swiss ETS would, however, not allow generating allowances from removal results (from sustainable biomass processing). If the scope of the ETS remains unchanged in this regard, the removal results achieved by WtE-CCUS would remain eligible for crediting under the VCS. But it is also possible that the ETS will eventually be modified to recognise mitigation results from storing CO₂ from sustainable biomass sources (removal results) as is also considered an option for the EU ETS.

7. EU Carbon Removal Certification Framework

Introduced as a component of the European Green Deal on 30 November 2022, the Carbon Removal Certification Framework (CRCF) represents an initiative of the EU Commission to enhance the tracking of carbon removal results in the EU. As the framework will only become operational in the coming years, the applicability to our case is uncertain: for example, the eligibility of entities outside the EU is unclear, though, given the importance of Norwegian storage sites, it is possible that results from the EEA might be accepted (then it is a matter of where the results occur). It appears probable that at least some types of VCS credits from CCUS projects (of those labelled as removals) could be incorporated under the CRCF. Credits produced in line with the CRCF might qualify for compliance use under EU regulations (perhaps including the ETS) and thus potentially fetch higher prices than purely voluntary credits.

8. Potential (future) crediting and monetisation options

International and national carbon crediting systems in most cases closely mirror the carbon project cycle outlined above (Section 4). Carbon credits that are generated following the requirements of an ETS or a national carbon tax can also be monetised by selling to entities that need to demonstrate compliance with their cap or to reduce their carbon tax burden. In some cases, the regulator specifies eligibility based on: a) the types of credits, b) the specific voluntary carbon standard, c) the types of use, d) the carbon market segments, and e) further credit attributes (such as the vintage, host country and credit programme).

Monetisation towards compliance can – where possible – offer more favourable demand–supply ratios and price levels compared to demand on the VCMs. ‘Soft’ attributes, such as sustainable development co-benefits, can also influence credit demand and price.

8.1 Article 6.4 – centralised mechanism

Though introduced via Article 6 of the Paris Agreement, Article 6.4 represents a standalone baseline and credit mechanism (A6.4M). It serves as a UN crediting mechanism fully under UN rules. It will follow a very similar carbon project cycle to that described previously, and methodologies under this mechanism may very much resemble those of established VCM standards. Credits (A6.4ERs) will be issued under the supervision of a UN supervisory body and will be internationally tradeable for countries to use towards NDC delivery (or voluntary offsetting or contribution claims). The A6.4M is expected to become the go-to source of credits for governments that need to purchase credits for achieving their NDC, which over time could become the largest source of demand for carbon credits. Given that the A6.4M has a unique position as a formal UN mechanism with UN-approved methodologies and requirements, it is expected to set the tone also for other crediting standards, which over time may adapt to become similar in their requirements.

8.2 ICAO – an emerging source of demand for credits

CORSIA was launched by the International Civil Aviation Organization (ICAO) in 2016. The main goal is to limit international aviation emissions to 2019 levels, and all participating airlines shall compensate for their emission increases with the purchase and surrender of eligible carbon credits. It is expected to be implemented in three phases: pilot phase 2021–23 (voluntary), first phase 2024–26 (voluntary) and second phase 2027–35 (mandatory).

Eligible standards include the VCS, American Carbon Registry (ACR), Clean Development Mechanism (CDM), Climate Action Reserve (CAR), Gold Standard (GS), China GHG Voluntary Emission Reduction Program, Architecture for Reducing Emissions from Deforestation and Forest Degradation and the Role of Conservation, Sustainable Management of Forests and Enhancement of Forest Carbon Stocks in Developing Countries (REDD+) Transactions, and Global Carbon Council (GCC). Not all credits are allowed from these programs, as several limitations have been defined. Limitations are set on the vintages of the activities (i.e. the crediting period must commence after 1 January 2016) or technology type. CORSIA is not expected to generate significant demand for eligible carbon credits during the pilot phase (IETA, 2022) due to the reduction in flights during COVID, but it may see greater demand in the first and second phases.

9. Barriers and opportunities for action

With CO₂ storage sites becoming operational and VCMs adopting full suites of relevant methodologies and tools for CCUS projects, there are no longer any fundamental barriers to pursuing crediting of WtE CCUS. Nonetheless, navigating the development of first-of-their-kind carbon projects requires addressing three barriers: a) clarity as to the eligibility of transboundary projects under the Swiss (inland) compensation system, b) international accounting of results and – linked to this – the question of whether an ITMO transaction is required to transfer credits to Switzerland, and c) clear arrangements among the partners to clarify ownership and accrual of carbon credits, as well as the ensuing sharing of the revenue among the many partners involved.

9.1 Request clarification of eligibility of transboundary projects for Swiss inland compensation

The implications of the question of where CCUS mitigation results are occurring extend far beyond international accounting rules and pertain even to whether an activity involving capture in Switzerland with storage abroad could principally be considered eligible under the Swiss compensation instrument. The question is whether capture by a Swiss entity would constitute the result having occurred in Switzerland, in which case the activity outlined here could be eligible as a domestic compensation project under the Swiss CO₂ law.

Alternatively, if the capture is considered a result that has been achieved abroad (in this case, in Norway), then it could be purchased as an ITMO and used towards the foreign credits part of the compensation obligation.

9.2 International agreement to clarify where results occur

A precondition for carbon crediting in general – and especially if Article 6.2 transactions are envisaged (or A6.4M credits) – is clarity as to where the results are generated in the value chain. It is unclear to date whether a removal (or an emissions reduction) is accruing at the site of CO₂ capture or at the site of CO₂ storage. Unfortunately, this has never been legally clarified, and there are good arguments for both.

This influences whether the CCUS value chain from WtE with capture in Switzerland, transport abroad and storage in Norway would be considered as either a) achieving a mitigation result in Switzerland (upon capture) or b) achieving a mitigation result in Norway (upon storage). In the former case, no international credit transaction would be needed for Switzerland to own credits. In the latter case, credits could be sold (as ITMOs under Article 6.2) to Switzerland, with corresponding adjustments in Norway and Switzerland. In our example, assuming Switzerland seeks to account for the mitigation results towards its NDC, in case a) Switzerland could directly report the results as a net reduction in emissions (in the waste sector) without international transfer of mitigation outcomes. This is because the capture – with the intent of storage – achieves the mitigation result domestically in Switzerland, even when the physical storage takes place abroad.

‘Whether the rules are interpreted such that a removal result is achieved in the CO₂-capturing country or in the CO₂-storing country will determine whether or not an ITMO transaction would take place.’

While the Swiss Federal Government and its Norwegian counterpart involved in this transboundary value chain have engaged in an ongoing exchange to resolve this question, its resolution is not yet clear. A resolution will eventually be required for transboundary cooperation, ideally in a manner that then becomes a standard international practice to ensure consistency (as Northern Lights will store CO₂ from multiple countries). Ideally, the solution would then be finally affirmed in the IPCC inventory guidelines.

With this national accounting uncertainty, there is potential also for misunderstandings at the project level as to where the mitigation result is achieved along the CCUS value chain and who among those involved in the value chain is the rightful owner of credits being issued.

Given that in case a) there is no ITMO transaction involved, all carbon revenue for CCUS value-chain implementation will need to come from domestic policy incentivisation via the waste-sector agreement, or (should the agreement be replaced by inclusion in the ETS) through the savings and opportunities for selling allowances, or from public procurement of VCM CCUS credits.

9.3 Institutional arrangements of ownership and revenue sharing

As described in Section 4, Step 0 of developing a WtE CCUS carbon project involves exploring and deciding on the most suitable institutional arrangements and drawing up the matching contractual arrangements, so that there is an effective project developer (either one of the value-chain partners, an aggregate entity comprising several partners, or a service-providing third party) and such that the requirements regarding reversal risk (as set out in the methodology and the reversal risk tool) are fulfilled.

In our view, this will have to be the first step towards a carbon project based on WtE CCUS.

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BP2a – International CCUS collaboration

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Blueprint 2b – International CCUS collaboration – Swiss CO₂ capture at a cement plant and storage in Iceland

DemoUpCARMA

Work Package 5: addressing policy, regulatory and acceptance challenges to enable CCUS deployment

Task 1: emissions accounting, reporting tools and climate finance mechanisms of negative emissions for national and transnational CCUS solutions

Zurich, 15 Dec 2023

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Table of contents

1. Summary	5
2. Background and objectives	8
2.1 Challenges for monetising CCUS activities beyond ETS	8
2.2 Blueprint focus	9
2.3 Objective	10
2.4 Materials and methods	11
3. Description of the value-chain use case	12
3.1 Description of the scope of activities	12
3.2 Technical feasibility and barriers	13
3.3 Relevant information on the value chain for crediting and monetisation	13
4. How to generate and monetise credits under the VCM	14
4.1 CCUS methodology beyond CCS+ Initiative	19
4.2 How to make VCM credits eligible for transfers under Article 6.2	19
5. Swiss compensation scheme	21
5.1 Procedure towards carbon credits	22
5.2 Eligibility of the proposed CCUS project value chain	23
6. Swiss emissions trading system	26
7. EU Carbon Removal Certification Framework	27
8. Potential (future) crediting and monetisation options	28
8.1 Article 6.4 – centralised mechanism	28
8.2 ICAO – an emerging source of demand for credits	28
9. Barriers and opportunities for action	29
9.1 Request clarification of eligibility of transboundary projects for Swiss inland compensation	29
9.2 International agreement to clarify where results occur	29
9.3 Institutional arrangements of ownership and revenue sharing	30
10. Bibliography	31

List of tables

Table 1: Project boundary	12

List of figures

Figure 1: Overview of the process for developing a Swiss Cement-CCS carbon project involving storage abroad to generate revenue	6
Figure 2: The value chain and monetisation option detailed in this blueprint	10
Figure 3: Overview of the four possible avenues of monetising mitigation results examined in the four blueprints	11
Figure 4: Criteria relevant to the integrity of carbon credits – to be demonstrated transparently by the standard	15
Figure 5: CCS Methodology, its modules for capture, transport and storage and accompanying tools applicable in this blueprint	16
Figure 6: The carbon project cycle from idea to issuance of credits	18
Figure 7: The core elements of a project design document (PDD)	18
Figure 8: Swiss compensation scheme procedure	23

1. Summary

This blueprint explains how to generate revenue from carbon credits from a Swiss cement plant with carbon dioxide (CO₂) capture, utilisation and storage with geological mineralisation abroad. It considers the implications of the Swiss Emissions Trading System and its limitations as well as the possibilities for generating credits under the voluntary carbon market and gives an outlook to the utilisation of other carbon markets. It explains under which circumstances credits would be transferable to Switzerland (should results be considered to accrue at the storage site abroad rather than upon capture in Switzerland).

This document is part of a suite of four blueprints produced under the DemoUpCARMA project to aid the monetisation and scaling of carbon capture, utilisation and storage (CCUS)¹ applications in Switzerland under voluntary and compliance markets, both domestic and international. The blueprints collectively assess the following market cases:

- certificate sales via the voluntary carbon market (VCM)
- domestic compensation instrument under the Swiss compliance market
- international transfer of mitigation outcomes achieved abroad
- emissions trading systems (ETs)

and the following CCUS applications:

- CO₂ capture from a biogas upgrade plant, a WtE plant and a cement plant
- CO₂ transportation via trucks, rail, ships and barges
- CO₂ storage in concrete, subsurface supercritical CO₂ storage and subsurface mineralisation.

To help project developers in their quest to monetise – and thereby enable – CCUS adoption, each blueprint presents:

- an overview of challenges for the monetisation of CCUS activities
- monetisation options for CCUS in voluntary and compliance markets
- step-by-step guidance to generate credits
- considerations for the monetisation of credits
- barriers and opportunities for action.

This particular blueprint explains the specific steps needed for developing a carbon project under the VCS, the role of the ETS, and opportunities for action toward a systematic monetisation of mitigation results from a CCUS value chain consisting of:

- CO₂ capture from a Swiss cement plant
- CO₂ transportation via trucks, rail, ships and barges
- CO₂ storage in geological formations with mineralisation as demonstrated in Iceland.

It guides through the process to monetise such a CCUS activity (Figure 1), from establishing a partnership along the CCUS value chain to selling and sharing the revenue from the carbon credits generated.

¹ This report, exclusively uses the term carbon capture, utilisation and storage (CCUS) to cover any type of activities ranging from carbon capture and storage in geological formations to carbon capture, utilisation and storage in durable products resulting in long-term storage.



Figure 1: Overview of the process for developing a Swiss Cement-CCUS carbon project involving storage abroad to generate revenue.

(Source: Authors, 2023)

Carbon credits can provide a revenue stream to cover the additional cost of implementing CCUS technologies in the cement sector beyond savings incurred by their compliance with an Emissions Trading System (ETS). Generating the carbon credits, however, is not straightforward. It involves complex procedures to ensure a high-quality standard and environmental integrity in the quantification and certification of emission reductions or removals through CCUS activities.

Used as a companion to formal documents setting out requirements and processes, this blueprint helps anticipate the main challenges for monetising CCUS from a Swiss cement plant. It contains a step-by-step guide to submitting a project to a voluntary carbon market standard for demonstrating compliance with the standards' requirements. Key challenges even before submitting a project are explained, such as defining which entity (among many involved along the value-chain) will be the project proponent to whom credits will accrue and how to arrange for the appropriate sharing of carbon credit revenues among value-chain partners. With an example, the blueprint illustrates how to describe the project scope, i.e., how to determine the project boundaries in time and space, and the suitability of the activity with carbon accounting methodologies. This document discusses the considerations and requirements for project development within the VCM. These aspects are systematically addressed in a designated Project Design Document (PDD). Under the framework of the Swiss compensation scheme, a corresponding document encompasses similar key topics such as the activity outline, baseline, and monitoring methodology. Complying with these requirements is crucial for meeting the Swiss compensation or VCM criteria and, more importantly, to ensuring a high-quality standard and high environmental integrity of the mitigation credits.

The blueprint, furthermore, provides guidance to navigate the evolving and increasingly complex carbon markets. In particular, it explains under which circumstances such a value chain may under international law be considered to achieve results at the point of storage (abroad) and what provisions then would apply for Switzerland to purchase and count these results domestically. This would involve an international transfer following UN requirements. For this, the blueprint explains key considerations of possible developments regarding compliance markets, notably the potential to generate credits under Paris Agreement Article 6.2 and the outlook to utilising the more formalised Article 6.4 to potentially achieve an even greater range of international demand for high-quality credits. The blueprint outlines expectations of market dynamics ranging from voluntary and compliance markets to empower cement sector actors seeking to get into CCUS leverage carbon markets to decarbonise their industry and achieve removals.

Entities subject to the EU ETS such as cement plants are not in principle excluded from crediting under voluntary carbon markets (VCS) or from international transfers under Article 6 even when they already experience the incentivisation flowing from reduced ETS compliance costs or even the

Blueprint 2b - International CCUS collaboration

possibility of selling surplus allowances. However, entities in the ETS need to demonstrate that these incentives are not sufficient for implementing and operating CCUS (see section 3). The blueprint thus outlines the limitations and conditions for the (partial) eligibility of cement-CCUS mitigation results under the VCS.

2. Background and objectives

Developing a CCUS industry is challenging: multiple interlinked sectors and actors need to cooperate based on the shared interest in generating revenue related to climate change mitigation results. This requires creating an ecosystem of compatible interfacing logistical, technological and contractual pieces working cooperatively across a significant number of private-sector actors and in compliance with carbon market rules, while also ensuring compliance with national accounting in multiple countries. The incentives under the Swiss and the EU's Emissions Trading Systems (ETS) have not been sufficient to mobilise CCUS. And despite advancements in pilot value chains funded by subsidies or induced by regulatory obligations, transitioning to a scalable business model reliant on carbon revenue or incentives from emissions trading remains challenging.

Currently, there are limited robust standards for tracking mitigation results from CCUS, despite relying on such results towards medium- to long-term mitigation goals. While initial CCUS pilot projects have accessed funds, scalable long-term funding for CCUS with clear climate benefits remains elusive. Effective climate action thus demands leveraging voluntary carbon markets (VCMs) to swiftly unlock revenue and draw lessons learned for regulatory approaches, many of which appear set to adopt key structures and methodologies from the first-mover VCM.

CCUS activities involve multiple sectors, sparking concerns of power disparities between highly capitalised established oil and gas companies (delivering underground carbon dioxide (CO₂) storage) and much smaller and novel carbon capture technology providers. This requires attention to ensure fair sharing of carbon revenue among partners.

2.1 Challenges for monetising CCUS activities beyond ETS

This blueprint addresses two challenges:

- 1) the lack of carbon market methodologies for tracking mitigation results from CCUS, and
- 2) the lack of clarity on accounting, responsibilities and ownership in carbon market projects within the complexity of CCUS hubs and clusters.

Need for a cohesive ensemble of carbon-tracking methodologies

The insufficient price levels of ETS allowances have not yet allowed scaling CCUS solutions. The absence of a unified carbon accounting methodology has hindered CCUS projects from accessing carbon markets as an additional source of revenue. Traditional methodologies have been narrow, focusing on specific project chains rather than the comprehensive industrial ecosystem needed for effective carbon management. This fragmentation has hampered the generation of reliable credits from CCUS projects, especially those in larger interconnected systems. However, recent efforts, led by the CCS+ Initiative in collaboration with Verra (associated with the Verified Carbon Standard (VCS)), aim to develop a comprehensive suite of methodology modules to address this gap.

The CCS+ Initiative introduces an advanced carbon accounting system for varied CCUS projects, using a modular approach for activities across carbon capture, utilisation and storage. A 'plug-and-play' system recognises shared infrastructures across CCUS technologies, enhancing adaptability to fit the numerous possible combinations across multiple hubs and clusters. The carbon accounting landscape had long been fragmented and lacked consistency across the emerging CCUS ecosystem. Though Verra and the Gold Standard have made progress, these standards would benefit from more stringent overall oversight to ensure long-term credibility via a coherent carbon

accounting framework that also conforms with evolving formal accounting rules under the Paris Agreement. High-quality, evolving methodologies can ensure transparency. Adopting stringent, up-to-date standards can streamline quality assurance, reducing costs and increasing efficiency throughout CCUS value chains.

Need for disambiguation of accounting, responsibilities and ownership

CCUS activities can achieve two different types of results, which need to be clearly differentiated depending on the source of carbon: reductions in emissions in the case of fossil carbon and removals of CO₂ in the case of biogenic carbon, which need to be transparently tracked and communicated. Other CCUS-specific ambiguities, particularly for CO₂ transport across national borders, can create confusion in regards to responsibilities that need to be clarified by private contracts among various partners along the value chain. As a result, the private sector faces ambiguities concerning ownership, liability and carbon-revenue accrual. Navigating these challenges requires clarification of rules at the international level (including regarding national greenhouse gas (GHG) inventories). It also requires consideration of technical and institutional aspects, such as needing to ensure that project owners have control over the durability of storage. Lacking clarity regarding project ownership and liability as well as the respective contractual assurance can become problematic in case of leakage, or when regulations and carbon market rules evolve. Identifying key stakeholders and creating clear arrangements are vital and need to draw from best practices and existing guidelines to maximise compatibility across multiple storage hubs and clusters of emission sources.

2.2 Blueprint focus

The focus of this blueprint is generating carbon credits from a Swiss cement plant with carbon capture, transport and storage abroad under the VCM standard VCS. Depending on the future praxis those results occur in Switzerland or at the storage site in which case credits would then be transferred under the Paris Agreements' Article 6 (see Figure 2). Section 3 provides further details.

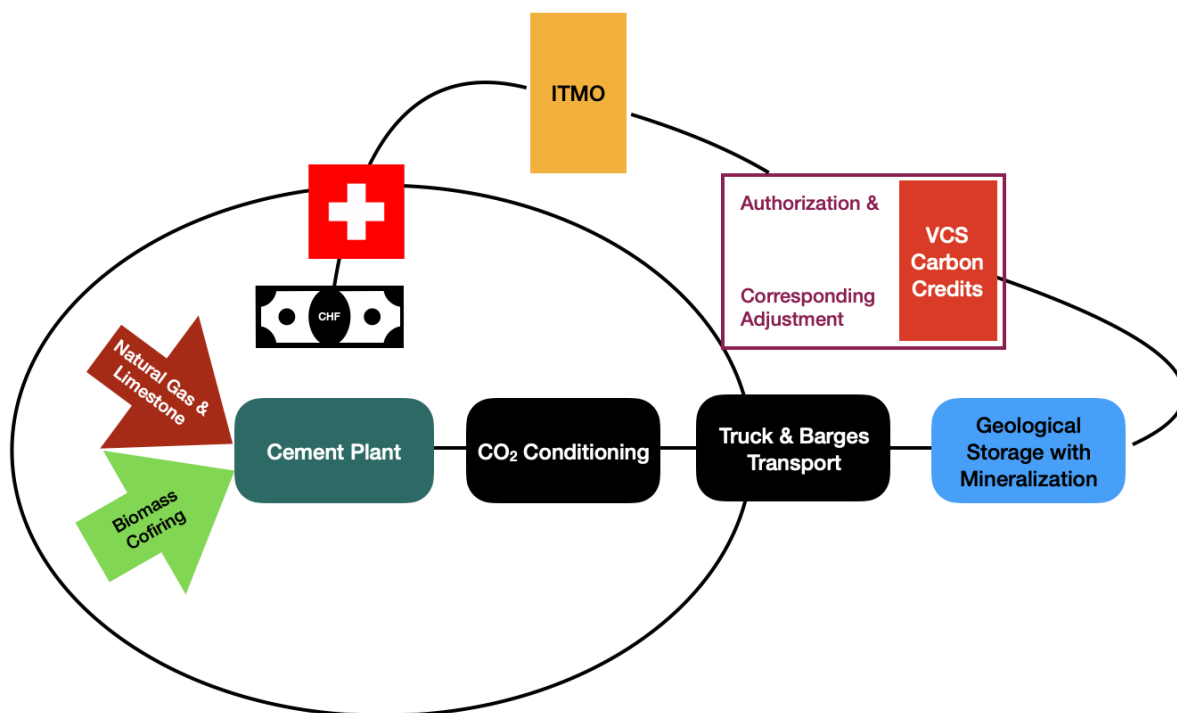


Figure 2: The value chain and monetisation option detailed in this blueprint

(Source: Authors, 2023)

2.3 Objective

The goal of this blueprint is to answer:

'How can a Swiss cement-CCUS project developer generate revenue based on the mitigation results of their activities in carbon markets and beyond?'

The VCM is the starting point as this is what the underlying ensemble of methodologies has been designed for. As existing standards do not yet provide robust methodologies for certifying complex CCUS activities, the blueprints build on a state-of-the-art carbon accounting infrastructure currently under development by the CCS+ Initiative for the VCS. The CCS+ methodologies are to provide a high-quality standard for the responsible adoption of CCUS activities (CCS+ Initiative, 2023). This enables project developers to fulfil the transparency and environmental integrity requirements of voluntary and eventually compliance markets. This blueprint shows the process to generate and sell carbon credits under the VCM, including guidance to define the project design document (PDD), which builds on methodologies' robust technical considerations. In a second step, the blueprint also explains the steps potentially necessary for making results available to be counted toward the Swiss mitigation goals.

While the blueprint starts with explaining the approach under the VCM and how voluntary credits can be used for transfers under the Paris Agreement Article 6.2 (upon authorisation and corresponding adjustments; see the second option in Figure 3), it also points to the generation of credits under the UN A6.4M and the role of savings or revenues for cement plants under the European emissions trading systems (ETS).

Blueprint 2b - International CCUS collaboration

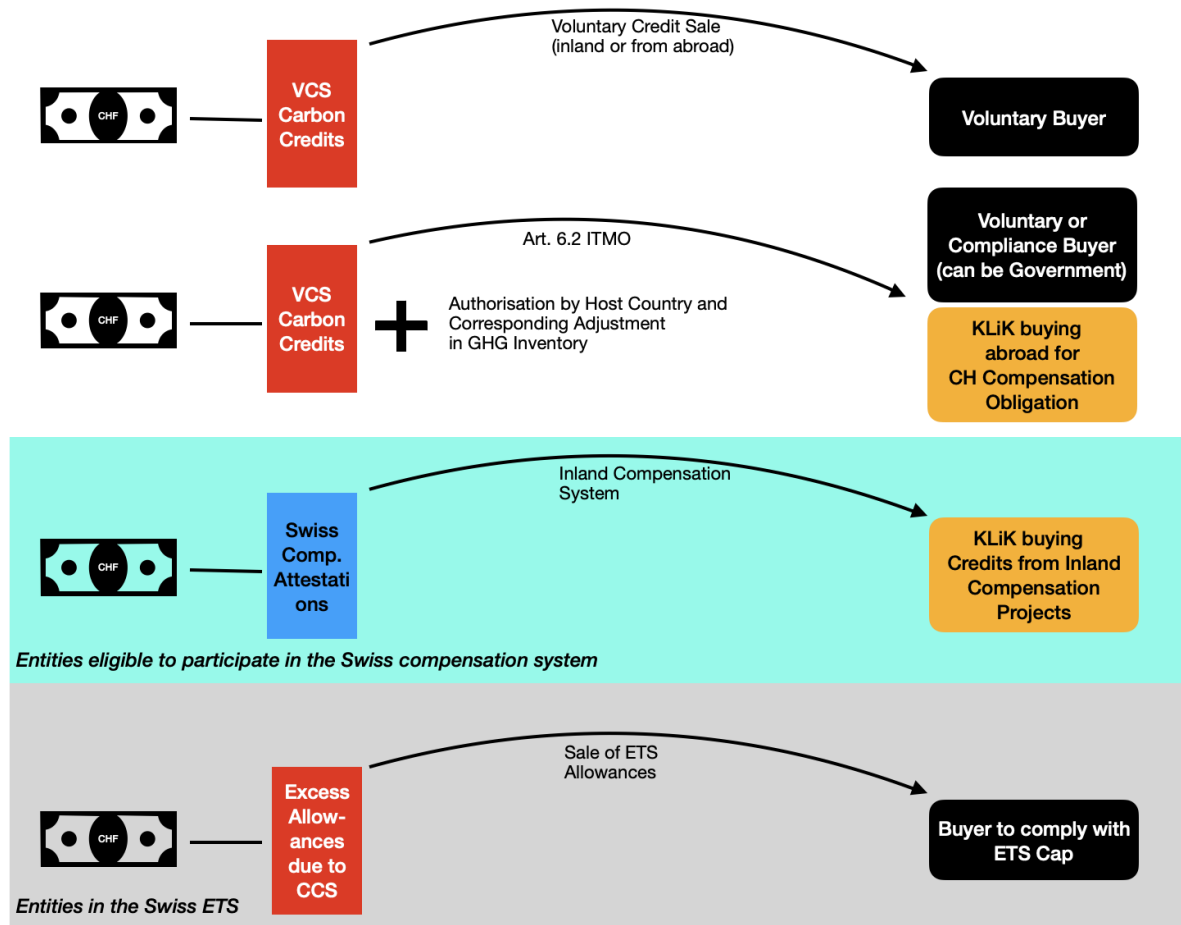


Figure 3: Overview of the four possible avenues of monetising mitigation results examined in the four blueprints; this blueprint's focus is on the second one albeit it is not certain that an ITMO transaction would have to be involved.

(Source: Authors, 2023)

2.4 Materials and methods

This blueprint draws primarily on the applicable baseline, and monitoring, reporting and verification (MRV) methodology, modules and tools. These were developed by Perspectives and South Pole with input from stakeholders in CCS+ and DemoUpCARMA. Secondly, blueprints and methodologies are informed by provisions in the contexts of GHG inventories, EU storage rules and EU carbon certification considerations, as well as the UNFCCC Article 6. Pertinent information on these matters is incorporated in condensed form to offer a cohesive guide to approaching international cooperation on transboundary CCUS value chains designed for maximum compatibility with these policy contexts, for the case of a Swiss cement plant and CO₂ capture with storage in e.g. Iceland.

3. Description of the value-chain use case

CCUS projects involve the capture of CO₂ from a point source or directly from the atmosphere. The captured CO₂ is typically compressed and transported by pipeline, ship, rail or truck to be injected into deep geological formations (e.g. deep saline aquifers, depleted oil and gas reservoirs, or reactive rock formations). Alternatively, CO₂ can be stored in the long term in building aggregates.

3.1 Description of the scope of activities

The value-chain case example outlined by this blueprint includes the collaboration between a cement plant operator in Switzerland capturing CO₂, transport of CO₂ for storage in geological formations involving mineralisation in a country in the EEA (e.g. Iceland though the rules would be likewise for equivalent storage sites elsewhere in the EEA).

A key aspect of developing and describing a carbon project (as shown in Section 4) is determining its boundaries in time and space. Table 1 outlines what this could look like in the case examined here.

Table 1: Project boundary

Geographical boundary	Refers to the location of the project activities.	Switzerland, countries through which CO ₂ transits (e.g. Germany, Netherlands), international waters, and country in which CO ₂ is stored (e.g. Iceland).
Temporal boundary	Refers to the timeframe during which the project activities occur and impact GHG emissions.	VCS crediting period for projects involving geological carbon storage: maximum of 42 years (a maximum of seven years, renewable up to five times).
GHG sources	All relevant sources of GHG emissions are identified and included within these boundaries.	Cement plant, conditioning leakage, transport leakage, energy required for conditioning, transport, and storage, storage site leakage.
Secondary effects²	The project boundary also considers secondary effects related to the project.	No secondary effects identified for the case of cement-CCUS.

(Source: Authors, 2023)

Cement plants are among the largest CO₂ point sources with around 3 MtCO₂ per annum. Many plants co-fire organic matter (alongside coal or gas) to lower their carbon footprint. The key trade-off in capture rates relates to the increased energy demand for both fuel and power.

² Most methodologies foresee a materiality threshold that allows cutting off secondary effects of irrelevant size to avoid unnecessary complexity.

3.2 Technical feasibility and barriers

Implementing cement CCUS is on a technical level a fairly well-established type of carbon project. However, the new type of geological storage as practised by Carbfix in Iceland has not been widely used at an industrial scale. Though the scientific findings suggest this to be a practicable and very safe form of storage, which might also positively influence public perception due to the inherent stability of storage, it is yet unclear how fast it can be scaled and how fast suitable storage sites can be established in various geographies. Nonetheless, there do not appear to be any glaring, insurmountable technical obstacles as of today. Numerous smaller operational challenges may, however, need to be anticipated especially in countries that do not yet have plans for CO₂ storage, and thus lack an industry ecosystem of actors familiar with the transport and storage infrastructure requirements.

3.3 Relevant information on the value chain for crediting and monetisation

For a cement-CCUS carbon project – particularly one that requires transport of CO₂ across a national border between Switzerland and countries in the EEA – there is a need to pinpoint where and to which partner in the value chain the mitigation result is considered to occur. This will determine, which country government would need to give authorisation and effect a corresponding adjustment as per the rules under the Paris Agreement Article 6 for international transfers of mitigation outcomes. This is to be clarified at the outset along with the choice, whether the project proponent is – for example – the cement plant operator or the storage site operator.

There are some implications of the fact that the cement sector is subject to the EU and the Swiss ETS: should the prices of allowances rise significantly under the ETS, the additionality of CCUS activities may not always be in place. This would then preclude crediting under the voluntary carbon market including for transfer under Article 6 for purchase by the Swiss government (seeking to meet its net-zero target).

A crucial piece of data in cases of cement plants with biomass co-firing will be the proportion of CO₂ stemming from sustainable versus non-sustainable sources (i.e. 'sustainable' biomass wastes versus non-sustainable biomass and fossil wastes). This distinction is vital for differentiating between emission reductions and removals concerning the baseline, the project and potential leakage emissions. To clarify, both fossil carbon and non-sustainable biogenic carbon point towards CO₂ reduction, while only sustainable biogenic carbon translates to CO₂ removal.

4. How to generate and monetise credits under the VCM

The VCM has grown in recent years and offers a meaningful source of revenue for climate mitigation results. The VCM involves the sale of carbon credits, which can be bought for voluntary offsetting, voluntary (non-offsetting) mitigation contributions or in some cases also for offsetting obligations (if additional requirements are met). Credits are issued through a formal process by standards such as the VCS and can be traded either directly or through intermediaries. Though often used to make carbon neutrality claims, they increasingly serve more broadly as a means to track mitigation results in a consistent and verifiable manner.

The process of generating carbon credits essentially serves to transparently demonstrate that the conditions for integrity are met by the proposed activity. The integrity of carbon credits requires transparently meeting the seven factors shown in Figure 4.

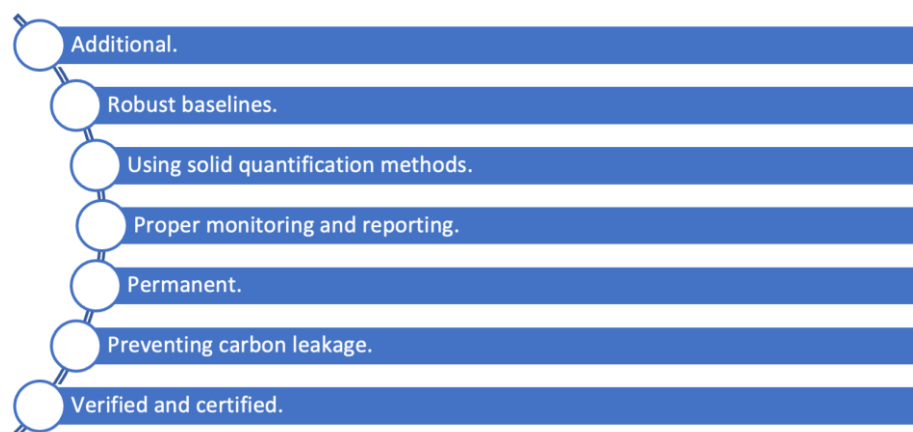


Figure 4: Criteria relevant to the integrity of carbon credits – to be demonstrated transparently by the standard

(Source: Authors, 2023)

Methodologies are vital for quantifying greenhouse gas benefits, generating credits and monetising them. These methodologies are regularly updated for accuracy and relevance. For this, specific methodologies have been developed under a voluntary carbon market standard – in our case, under the Verified Carbon Standard (VCS), the ‘Methodology for Carbon Capture and Storage’ is applicable along with the:

- module for CO₂ capture from industrial processes,
- consolidated module for CO₂ transport,
- module for CO₂ mineralisation in igneous rock formations.

In addition to the methodology and its modules, there are two relevant tools (see Figure 5): one to differentiate emissions reductions and removals (*Tool for differentiating reductions and removals in CCS projects*), and another in case an activity is subject to a compliance market system and would like to also benefit from voluntary carbon market revenue (*Tool for Baseline Quantification and Allocation of Project Emissions in Projects with VCS and non-VCS-CO₂ flows in Carbon Capture and Storage Projects*). The latter is needed to further differentiate between the CO₂ from VCS and non-

Blueprint 2b – International CCUS collaboration

VCS project activities, as CO₂ leaving the project boundary (i.e. non-VCS CO₂) must be quantified and excluded from the project's emission reductions or removal results that may be credited in the VCS.

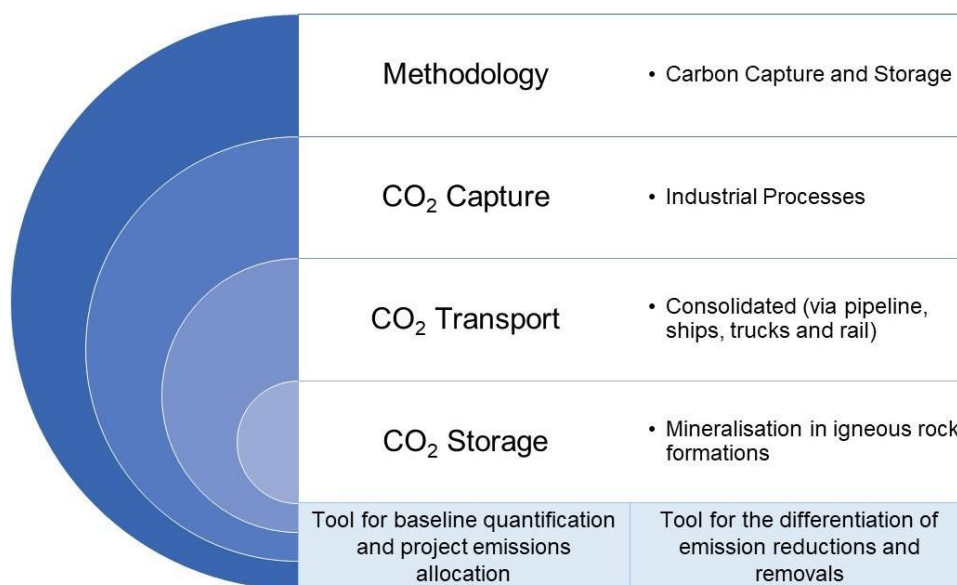


Figure 5: CCS Methodology, its modules for capture transport and storage and accompanying tools applicable in this blueprint.

(Source: Authors, 2023)

Examining early the information required – by the methodology, modules and tools – from the prospective project and the various partners involved, will make it easier to prepare the necessary institutional and contractual arrangements for partners along the value chain as outlined in the following step 0.

Step 0: Preparations for a transboundary CCUS value chain

The complexity of CCUS value chains requires a number of measures even before formally starting the carbon project development under a specific standard. This notably includes figuring out the most suitable institutional arrangements along the value chain, including signing agreements to meet VCS requirements. Important requirements to consider at the outset (for all projects involving geological storage of CO₂) are outlined in the Geologic Carbon Storage (GCS) Requirements (Verra, 2023b). The GCS is the key tool for ensuring inter alia that the entity receiving credits is also held responsible should reversal occur.

Alternative modes of collaboration should also be considered. For example, instead of choosing one of the partners in the value chain to act as the project proponent and project developer, partners could form a legal entity for the purpose of developing the carbon project. A third model is that an outsider-professional project developer acts as the project developer on behalf of the value-chain partners, which offers the advantage that in some cases such a project developer takes on the financial cost and risk of the project development itself.

Another important tool that may be considered at the outset is the Non-Permanence Risk Tool (NPRT)(Verra, 2023a), which offers an evaluation of reversal risk. Early consideration of reversal risk

may help structure contractual arrangements for dealing with the consequences of reversals among value-chain partners should it occur later on (e.g. to avoid unduly placing the financial burden on certain partners or failing to ensure appropriate incentives for the partner responsible for storage).

Furthermore, decisions need to be taken at the outset regarding the envisaged accrual and use of credits inter alia to prevent double-counting issues. This includes whether – given that the results accrue abroad – an international transfer (back to Switzerland) is envisaged as an Article 6.2 internationally transferred mitigation outcome (ITMO) (requiring corresponding adjustment). Similarly, it may be worth considering whether the share of removals in the results may be marketed separately (targeting buyers who are willing to pay a premium for innovative removal credits) and for this, a clear distinction between both types of results is required (using the corresponding tool).

For any ambiguities that imply decisions by governments (potentially in bilateral state contracts), the resolution should be proactively sought from the respective authorities. This concerns: a) cases where there is ambiguity as to where results occur, b) whether consequently an Article 6.2 transaction is envisaged and c) whether the activity may be eligible for the Swiss domestic compensation instrument as a foreign-compensation project. A common understanding of the technical, legal and contractual requirements and associated responsibilities among partners involved is key to developing the appropriate contractual arrangements as the basis for collaboration.

The following Steps 1–6 are part of the so-called ‘carbon project cycle’ exemplified hereafter for the VCS.

Step 1: Activity design

The process, as demonstrated in the example of the VCS, is very similar in most standards and is often referred to as the ‘carbon project cycle’. The key phases are shown in Figure 6. The process for carbon credit issuance typically begins with a PDD submission by the activity developer. This document outlines the activity, baseline and monitoring methodology. An independent third party validates the activity before registration. Once operational, the developer monitors and reports emissions reductions as per the PDD. The outcomes are then independently verified for carbon credit issuance.



Figure 6: The carbon project cycle from idea to issuance of credits

(Source: Authors, 2023)

This is the most work-intensive phase for the project proponent. It culminates in the preparation of a Project Design Document (PDD), which captures all relevant information as required by the methodology (including for additionality demonstration, baseline identification and the monitoring

plan). PDDs serve a key role up to validation as they demonstrate a proposed project's compliance with the conditions for integer carbon projects. The PDD's core elements are shown in Figure 7.

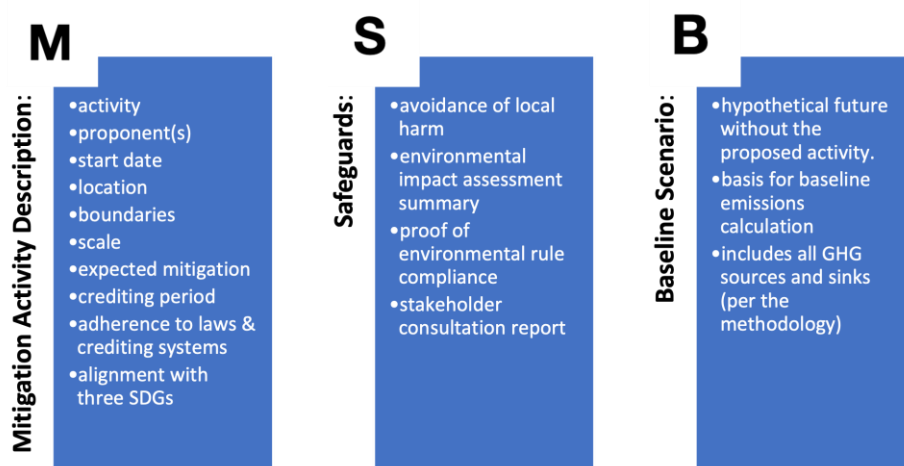


Figure 7: The core elements of a project design document (PDD)

(Source: Authors, 2023)

A central element in developing the PDD is the definition of the project boundaries, which is particularly challenging in the case of CCUS activities; while in the most simple case, the project comprises of a single capture, transport and storage facility, it is also possible that multiple capture facilities are included through a shared storage facility, or vice-versa that CO₂ captured from a single site is stored at multiple sites. For all these processes, the project boundary includes electricity, fuel, and material inputs as well as their associated emissions – including venting and fugitives.

Another key piece is the setting of the baseline, which in the case of adding carbon capture (for storage) to an existing cement plant essentially assumes a continuation of CO₂ emissions corresponding to the mass input of waste (i.e. absence of CO₂ capture from the facility). The baseline emissions can be determined by the amount of CO₂ injected at storage sites. To allow separate selling removal and emissions reduction credits from cement production with mixed fossil and biological inputs, the *Tool for differentiating reductions and removals in CCS projects* sets out the steps for a differentiated baseline (which is a precondition for differentiating results).

The PDD will also need to demonstrate additionality – to show that without carbon revenue from credit sales, CCUS would not be done. This is crucial for the integrity of carbon markets and ensuring efficient mitigation. For CCUS on a cement plant, its proof needs to be provided following the guidance of the CCUS methodology in three steps: 1) Regulatory Surplus, 2) Implementation Barrier and 3) Common Practice. This means that 1) the project is delivering mitigation beyond regulatory requirements, 2) that a financial barrier is in place and 3) that the activity is not (yet) common practice. Projects that pass all three of these steps are considered additional. In the case of biomass cofiring it is possible that cement-CCUS activities might – partly – be allowed to follow a simplified approach, but this remains to be seen. Demonstration of the regulatory surplus will be required in any case.

In the PDD, the proponent will also need to present the monitoring plan. This plan anticipates the monitoring activities that will be required during the monitoring period. It indicates the physical

Blueprint 2b – International CCUS collaboration

equipment to be used (e.g. meters), and the various partners' responsibilities and processes for collecting, processing and reporting data, as required by the methodology. It defines the parameters that need to be measured, their accuracy and the measurement frequency.

Step 2: Validation

Upon submission of a PDD by the project proponent to the standard body, the validation process starts. It involves a third-party validation/verification body (VVB) – approved by the carbon credit standard – which independently checks if the proposed project meets the standard's requirements. The first step of validation is a public review for about a month, followed by desk evaluation and then a site visit by the VVB. Based on these inputs, the VVB examines the accuracy of claims in the PDD, and either recommends the project for registration or suggests changes before it can be registered.

Step 3: Registration

Upon validation, the carbon standard performs a completeness check and registers the project in its registry. This enables the project owner to generate carbon credits for an initial period, called the crediting period. The length of the crediting period is set by the standard and can vary for different project types. For projects including geological carbon storage, the VCS has set the project crediting period to seven years, renewable up to five times, with a total project crediting period not to exceed 42 years to consider the longer lifespan of such projects.

Step 4: Monitoring and reporting

Upon registration and the start of activities, the MRV of results starts. A monitoring report is prepared following the data and information requirements set out in the latest VCS requirements for geological carbon storage and the respective methodology and modules. If a loss of containment occurs, the procedures outlined in the VCS Program (Verra, 2023c), the GCS requirements and the GCS NPRT shall apply.

Step 5: Verification of results

The report is verified by a VVB and the project proponent can then file a credit issuance request to the carbon standard.

Step 6: Issuance of credits

If everything is in order, credits will be issued in the registry and transferred to the proponent's account. Active credits can then be sold to gain revenue.

Step 7: Sale of credits

There are two key types of buyers: intermediaries/market aggregators, and end users. The latter include individuals, businesses and governments, but for project proponents with a small portfolio, they will be difficult to reach. Intermediaries include brokers, traders and exchanges (e.g. Carbon Trade Exchange (CTX), the CME Group and Xpansiv), which tend to charge a fee ranging from 5% to 20%. The sale can happen either before credit issuance (via an Emission Reduction Purchase Agreement (ERPA)) or after issuance. ERPAs under the VCS follow a template (IETA, 2023), which establishes roles, rights and responsibilities regarding project risks besides price, amount and credit delivery timeline. Another option for project initiators is partnering with activity development partners, who accompany the project from its inception to issuance and in some cases front the associated expenses to in turn be remunerated with a portion of credits generated later.

Removal-based credits are expected to fetch a higher price than those representing emission reductions, especially those that can clearly demonstrate durable storage.

4.1 CCUS methodology beyond CCS+ Initiative

Unlike other alternatives, the CCS+ carbon accounting infrastructure offers a unique modular ‘plug-and-play’ system approach to properly incorporate a wide set of possible project configurations. The aim is to include the majority of the current CCUS activities, and by addressing each technology type separately, future solutions can be effectively integrated into the infrastructure.

Today technology and industry players in the CCUS space offer a wide range of carbon capture, transport, utilisation and/or storage solutions. All these solutions need to be addressed and accounted for in their unique way. Methodologies are usually focused on specific technologies or define a set of eligible activities. This potentially leads to mitigation activities from one emitting sector not being eligible under the same accounting methodology due to different use of technologies or project activities. This is where the CCS+ initiative accounting structure would come into play.

In addition to the methodologies developed by the CCS+ Initiative under the VCS, various other carbon standards are actively working on the development of robust accounting methodologies to tackle the diverse and complex topic of CCUS. However, apart from the geological carbon mineralisation module development under the CCS+ Initiative, none of the other carbon standards endorsed by the International Carbon Reduction and Offset Alliance (ICROA)³ currently include the injection of CO₂ into reactive rock formations where it is stored through geological mineralisation. Geological storage options are currently limited to saline aquifers and depleted oil and gas reservoirs⁴.

Generally speaking, all standards, which are discussed in this blueprint, follow the same goal of developing rules, requirements and procedures for the design, development, monitoring and reporting of carbon projects which then results in an emission reduction or removal. Yet, when examining individual technology groups and solutions in isolation, rather than considering the entire value chain as a whole, the CCS+ initiative can craft a more robust carbon accounting mechanism for diverse project value chains.

4.2 How to make VCM credits eligible for transfers under Article 6.2

Under the Paris Agreement, countries can cooperate to achieve their NDCs based on the authorised transfers of ‘mitigation outcomes’ (which then become ITMOs). ITMOs can also be used towards obligations on international aviation under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

Authorisation by the country government in which the activity takes place is a precondition for ITMO transfer. Providing such authorisation commits the government from which the credits originate to

³ ICROA collaborates with various stakeholders in the voluntary carbon market, including project developers, carbon standards, and businesses seeking to offset their carbon emissions, promoting high standards and best practices in the voluntary carbon market. It ensures measurable, permanent, additional and independently verified emissions reductions.

⁴ Excluding Enhanced Oil Recovery (EOR).

Blueprint 2b - International CCUS collaboration

apply a so-called 'corresponding adjustment' (CA) to its GHG inventory. It is important to highlight that CAs do not alter the national GHG inventory but rather serve as adjustments to the emission balance, reflecting the emissions source under NDC targets. When a country uses the ITMO to achieve NDC targets, the buyer country also applies CA in its inventory. In most cases, ITMO transfer will rely on crediting via an established VCM standard (notably including the VCS), but countries can in principle also develop their own crediting systems if both buyer and seller countries agree on the requirements. Credits authorised as ITMOs have a broader demand base, including governments, airlines and voluntary buyers, and are likely to fetch a higher price. Credits without CA are increasingly seen as unfit for compensation and carbon neutrality claims, meaning that over time voluntary buyers will be willing to pay a premium once CA and ITMO transfers are operational at national and UN levels in one to two years.

Switzerland and other countries are already engaging in purchasing contracts with entities abroad – and with their respective governments – to determine quantities, conditions and responsibilities for carbon credit generation and ITMO transactions. So the example – a European cement-CCUS crediting activity resulting in the transfer of ITMOs to Switzerland – outlined in this blueprint is indeed possible.

5. Swiss compensation scheme

The Swiss compensation scheme is driven by the mandate outlined in the country's CO₂ Act (Federal Assembly of the Swiss Confederation, 2011), which requires fossil-fuel importers to offset a specific portion of their emissions. To meet this legal obligation, the KliK Foundation acts as an intermediary, connecting fossil-fuel importers with emission-reduction projects⁵ that generate carbon credits. These carbon credits from the approved projects are sold to fossil-fuel importers to offset their carbon emissions. The compensation scheme distinguishes between domestic projects within Switzerland and those undertaken abroad. The compensation obligation is defined as a specific percentage of the overall emissions produced by the imported fuels, which have to be offset partially in Switzerland and internationally. For a more in-depth exploration of the Swiss domestic compensation scheme and further details on additional CCUS activity support funded by unused funds from KliK's predecessor, the Climate Cent ('Klimarappen') Foundation, please refer to a separate document developed under the DemoUpCARMA project (South Pole, 2023).

This chapter is dedicated to providing prospective Swiss cement sector CCUS project developers with an overview of the applicability of the Swiss compliance scheme. It is important to state upfront, that the cement sector being subject to the Swiss ETS (as well as the EU ETS) cannot credit emissions reduction results under the Swiss compensation instrument. It may, however, credit removal results from the cofiring of sustainable biomass (as long as the latter is not within the scope of the ETS).

The chapter describes the project development under the Swiss compensation system, which shares similarities with the corresponding process under the VCM. Nevertheless, within the compliance scheme, several processes and structures are different (e.g. relevant documents regarding the registration of a climate project). Under the VCM, a clear distinction is drawn between methodology and project development. While a methodology defines standardised rules for executing, monitoring and verifying emission reductions, ensuring consistency across projects, the PDD describes unique project-specifics that apply a methodology, detailing project specifics and serving as evidence for each individual carbon offset project. In contrast, in the Swiss compensation system, these are combined into a joint project description and a monitoring plan. Nevertheless, they all include critical elements such as additionality, baseline definition, MRV processes, system boundaries, leakage and conservative CO₂ reduction quantification. Unlike the VCM, where project proponents can potentially apply an existing standalone methodology to their project, Swiss compensation mechanisms require the development of all relevant documents for each project.

Another notable feature of the Swiss compliance scheme is the compensation obligation imposed on the KliK Foundation. Securing Swiss 'attestations,' hereafter referred to as carbon credits, is subject to negotiations with project developers. It is essential to recognise that buyers in the VCM may also become potential purchasers of these credits. Typically, project proponents engage in ongoing discussions with KliK throughout the registration process with FOEN. A process, detailed later in this chapter, which includes the option to have a 'project outline' document evaluated by a validator and verifier (VV), providing an initial estimate of certificate quantities and the project's likelihood of acceptance and registration. Early discussions are thus relevant for financial assessments during project development.

⁵ The Swiss compensation scheme allows the development of single projects or programs that group several activities with common purposes. For simplicity, this document only refers to projects.

The following chapters provide an overview of the registration process for a cement-CCUS project with storage abroad, while also highlighting requirements and general principles. For an in-depth description, please refer to the document provided by FOEN (FOEN, 2022). The overview and information on the Swiss compensation scheme are extracted from the same document.

5.1 Procedure towards carbon credits

In the Swiss compliance market, the procedure for generating carbon credits closely mirrors the carbon project cycle previously outlined for the VCM, as depicted in Figure 6. Figure 8 provides a visual representation of the application process (Steps 1 to 3), and the ongoing monitoring, verification and transfer of carbon credits (Steps 4 to 6). In addition to these six steps, the figure emphasises the various documents that require authorisation, validation or verification by the involved stakeholders. In our project example, these stakeholders include FOEN in Switzerland, a VV (a third-party validator, similar to a VVB in the VCM) in Switzerland as the host country and all partner countries within the CCUS value chain.

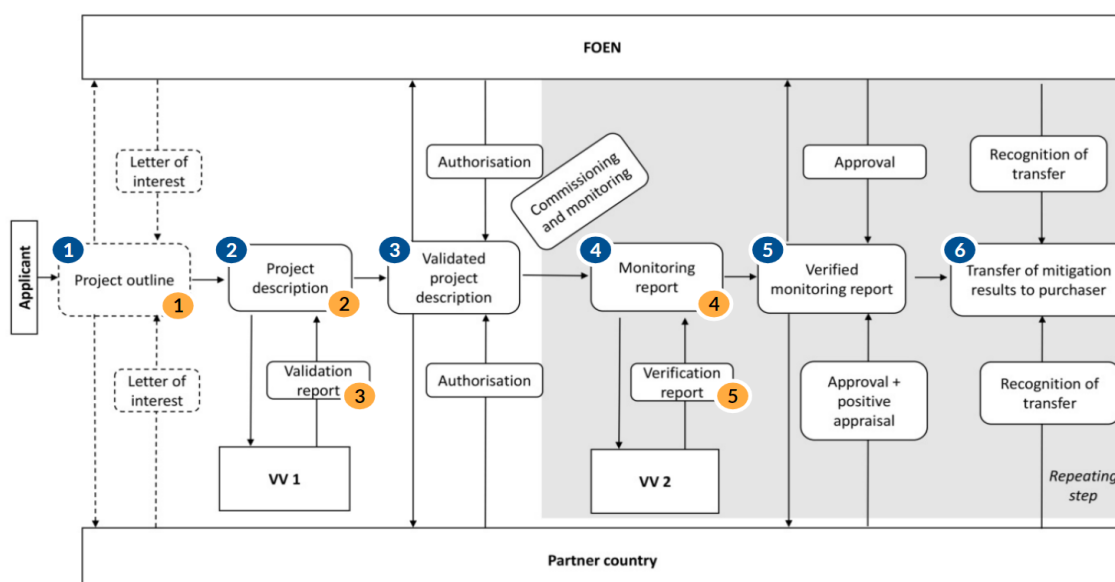


Figure 8: Swiss compensation scheme procedure (blue circles indicate carbon project cycle steps; orange circles indicate relevant project development documents⁶ necessary for application and ongoing monitoring, verification and credit issuing cycles)

(Source: adapted from FOEN, 2022)

Step 1: Project outline (optional)

In the first optional project outline, the developer can submit a project outline document to the FOEN and the partner country. This document serves as a preliminary assessment and a first eligibility judgement is assessed. Critical issues include additionality, differentiation from other climate policy instruments and preliminary calculation of expected emission reductions.

⁶ Procedures and templates for project development can be found on FOEN's website (FOEN, 2023b).

Step 2: Project description and validation

A detailed project description includes the following information such as: A detailed project description, an economic feasibility analysis, reference scenario development, differentiation from other climate policy instruments, a calculation method for determining emission reductions, a monitoring plan, and the validation report. The validation report is the revision of the project description by a FOEN-approved VV.

Step 3: Authorisation

After the VV approves the project description via the validation report and receives authorisation from FOEN and the respective partner countries involved along the project value chain, the project is eligible to commence the annual, ongoing Monitoring, Reporting, and Verification (MRV) process.

Step 4: Monitoring

The project description defines the start date for monitoring emissions and the method for demonstrating emission reductions. Typically, monitoring begins when the project becomes operational. The monitoring report demonstrates the emission reduction according to the monitoring plan outlined in the project description for each year. The monitoring report has to be verified by the VV.

Step 5: Approval by FOEN and partner countries

The verified monitoring report must be approved by the FOEN and partner countries.

Step 6: Transfer of mitigation results (carbon credits)

Carbon credits are transferred to the KliK Foundation.

5.2 Eligibility of the proposed CCUS project value chain

As of the revision to the CO₂ Ordinance in June 2022 (Federal Assembly of the Swiss Confederation, 2012), CCUS projects involving long-term storage in biological or geological formations, or non-organic building materials (e.g. concrete) have become eligible for the generation of carbon credits within the Swiss domestic compensation scheme.

All project developers need to set up a project description which will assess the eligibility of the proposed project in detail (Step 2 of the carbon project cycle). Below, several issues, relevant to the specific project value chain described in this blueprint are discussed.

Compliance with applicable legal provisions, differentiation from other climate policy instruments and avoidance of double-counting

Similar to projects in the VCM, projects under the compensation system must demonstrate compliance with other relevant legal provisions, which in this case includes all national legislation guided by the EU CCS directive. It must also show that there is no regulatory overlap, with other climate policy instruments, which would create double incentives. This means that crediting of emissions reductions results from cement plants subject to the EU ETS cannot be eligible for crediting under the Swiss compensation system as explicitly stated in Art. 5 para. 1 let c No 2 of the CO₂ Ordinance (Federal Assembly of the Swiss Confederation, 2012) only emissions which are not covered by an emission trading system are eligible under the Swiss compensations scheme. As long

as the EU ETS, however, is not reformed to include results from sustainable biomass (resulting in removal) such results – corresponding to the CO₂-capture quantities of biomass cofiring – could in principle be eligible.

To demonstrate compliance with the legal provisions of countries in which project activities are taking place, bilateral climate agreements⁷ are a necessary precondition to carrying out projects in foreign countries under the Swiss compensation scheme. Currently, Switzerland has no such agreement with Iceland and as of today.

Permanence of carbon storage

Under the Swiss compensation scheme, projects need to demonstrate a CO₂ storage of at least 30 years, regardless of the project duration (see CO₂ Ordinance Art. 5 para. 2). These requirements can be met by all geological storage sites which are available today, most aiming for long geological-time scales (e.g. thousands of years). The question regarding liability for the stored CO₂ should be answered in a bilateral agreement between the two countries. As mentioned in Section 4 (Step 0) documents from the Vera, namely the NPRT and the GCS requirements can help inform the project's approach towards liability and storage requirements.

Demonstration of additionality

Additionality under the Swiss compensation scheme is demonstrated by providing evidence that the project would not be economically viable without the revenue from the carbon credits for the entire duration of the project^{8,9}.

This can be shown in one of the following ways:

- Simple cost analysis: As it would be the case for this project value chain, if a project has no other revenue streams apart from the sales of the carbon credits, a simple cost analysis is used. Demonstrating that the project is not profitable and less viable than the most likely alternative scenario.
- Investment comparison analysis or benchmark analysis: Key financial indicators such as NPV or IRR are compared between the project scenario and the alternative scenarios. An additional sensitivity analysis is done, to demonstrate the financial assessment is robust when assumptions are adjusted.

Projects might still be additional even though they are financially viable. In this case, a barrier analysis can demonstrate that the project is facing barriers such as technical difficulties or lack of trust among customers. In addition to the economic analysis described above, the project developer must show that the project is not common practice. The project activities described in this blueprint are far from being common practice, and as already mentioned, the only source of revenue would come from the sales of carbon credits.

⁷ A bilateral climate agreement that governs cooperation between two countries and establishes the legal framework for the implementation of climate mitigation activities. Including a clear delimitation from partner countries nationally determined contribution (NDC). A list of bilateral agreements between Switzerland and foreign countries can be found on the FOEN website (FOEN, 2023a).

⁸ It is essential to include all types and sources of revenue. These include development assistance from donors, other climate finance mechanisms, public funding or other non-refundable payments.

⁹ The economic feasibility analysis is based on UNFCCC's Tool for the demonstration and assessment of additionality (UNFCCC, 2012).

Possible project duration

The Swiss compensation scheme, which obligates fuel importers to offset a portion of their emissions, was established based on the CO₂ Act, which is in force until the end of 2030. Without legislation to extend this policy, fuel importers would no longer be bound to offset their emissions from 2031 onward. Consequently, project developers are left with no assurance of continued demand, which diminishes the Swiss compensation systems' appeal for cement-CCUS project development, investments for which typically are on the order of dozens of millions (Sustainability in Business Lab, 2021).

Determination of reference scenario

The reference scenario is the most likely alternative to the project scenario, and generally the most economically attractive scenario. Defined once at the beginning of a project it serves later as a yardstick to compare the actual project emissions for quantifying mitigation results that may be credited. For cement-CCUS in an EEA country, that country's regulatory environment will be important to determine the reference scenario. In the absence of regulation that requires the use of CCUS in the cement sector, the reference scenario may be continued emission of all process and fuel-related CO₂ emissions at the projected rate of cement production.

Monitoring plan, monitoring report, and quantification of emission reductions

The monitoring plan, a crucial component of the project description and initial authorization process, outlines all relevant parameters and data to be measured and reported throughout the project's lifecycle. It provides specific requirements for handling data and methods employed to calculate emission reductions. This comprehensive monitoring plan serves as a step-by-step guide, enabling project proponents, third-party validators, and the FOEN to precisely calculate and understand actual emission reductions in the yearly monitoring report. In cases where a parameter cannot be measured precisely, the estimate must be as accurate as possible, which requires the consultation of supporting scientific measures. Moreover, all emission reductions or parameter estimations must be made conservatively, following the principle of conservativeness, to prevent any overestimation. The yearly monitoring report, verified by the VV and the FOEN, calculates emission reductions for a given year by deducting project emissions and associated project leakage¹⁰ from the reference scenario.

¹⁰ Leakage refers to the change in emissions beyond the project activities that are not directly attributed to but influenced by the project. It can have either a negative impact, resulting in increased emissions, or a positive impact, leading to more emission reductions. Unless negligible, leakage emissions must be considered in the final emission reduction calculation. An example of leakage would be the necessity to offset the reduced energy output and increased use of fossil fuels due to the diversion of biomass from a waste incineration plant to a biogas plant.

6. Swiss emissions trading system

The Swiss ETS incentivises CCUS activities of cement actors in Switzerland, whereby emissions that are verified and permanently stored eliminate the need to surrender emission allowances. So, the Swiss ETS represents an important consideration for Swiss cement-CCUS activities, although the price level of allowances may not induce sufficient incentives and certainty of cost-savings or revenue. Generating revenue from CCUS is possible in case of overachieving the allocated cap which puts the cement plant operator in the position of selling excess allowances to generate carbon revenue.

In the current form of the ETS, removals from cement-CCUS are, however, not incentivised by the ETS as capture and storing CO₂ on the portion of carbon stemming from sustainable biomass is disregarded. If the scope of the ETS remains unchanged in this regard, only emissions reductions from cement-CCUS would be considered. However, it is possible that the ETS will be modified in the medium term to recognise mitigation results from storing CO₂ from sustainable biomass sources (removal results).

7. EU Carbon Removal Certification Framework

Another potential revenue source for Swiss cement-CCUS – in case of biomass cofiring – is the Carbon Removal Certification Framework (CRCF) introduced as a component of the European Green Deal on 30 November 2022 and currently being developed. It represents an initiative of the EU Commission to enhance the tracking of carbon removal results in the EU and eventually facilitate generating carbon revenue from removals such as those that may be achieved when cement plants capture and store CO₂ from sustainable biomass sources. As the framework will only become operational in the coming years, the applicability and level of financial relevance in our case is uncertain: Whether results generated outside the EU can be certified under the CRCF is doubtful. Should that, however, be the case, it appears probable that VCS credits labelled as removals – including from cement-CCUS involving biomass cofiring – could be incorporated under the CRCF. Credits produced in line with the CRCF might qualify for compliance use under EU regulations (perhaps including the ETS) and thus potentially fetch higher prices than purely voluntary credits. But this remains highly uncertain for now.

8. Potential (future) crediting and monetisation options

International carbon crediting under the centralised Article 6.4 mechanism may in the future offer further opportunities for unlocking premium prices for credits – beyond those achieved when transferring mitigation outcomes under the Paris Agreement 6.2. Furthermore, ICAO may emerge as a growing source of demand for credits to which both VCM credits and Article 6.4 credits are eligible in principle.

8.1 Article 6.4 – centralised mechanism

Though introduced via the same Article 6 of the Paris Agreement, Article 6.4 represents a standalone baseline and credit mechanism (A6.4M). It serves as a UN crediting mechanism fully under UN rules. It will follow a very similar carbon project cycle to that described previously, and methodologies under this mechanism may very much resemble those of established VCM standards. Credits (A6.4ERs) will be issued under the supervision of a UN supervisory body and will be internationally tradeable for countries to use towards NDC delivery (or voluntary offsetting or contribution claims). The A6.4M is expected to become the go-to source of credits for governments that need to purchase credits for achieving their NDC, which over time could become the largest source of demand for carbon credits. Given that the A6.4M has a unique position as a formal UN mechanism with UN-approved methodologies and requirements, it is expected to set the tone also for other crediting standards, which over time may adapt to become similar in their requirements.

8.2 ICAO – an emerging source of demand for credits

CORSIA was launched by the International Civil Aviation Organization (ICAO) in 2016. The main goal is to limit international aviation emissions to 2019 levels, and all participating airlines shall compensate for their emission increases with the purchase and surrender of eligible carbon credits. It is expected to be implemented in three phases: pilot phase 2021–23 (voluntary), first phase 2024–26 (voluntary) and second phase 2027–35 (mandatory).

Eligible standards include the VCS, American Carbon Registry (ACR), Clean Development Mechanism (CDM), Climate Action Reserve (CAR), Gold Standard (GS), China GHG Voluntary Emission Reduction Program, Architecture for Reducing Emissions from Deforestation and Forest Degradation and the Role of Conservation, Sustainable Management of Forests and Enhancement of Forest Carbon Stocks in Developing Countries (REDD+) Transactions, and Global Carbon Council (GCC). Not all credits are allowed from these programs as several limitations have been defined. Limitations are set on the vintages of the activities (i.e. the crediting period must commence after 1 January 2016) or technology type. CORSIA is not expected to generate significant demand for eligible carbon credits during the pilot phase (IETA, 2022) due to the reduction in flights during COVID, but it may see greater demand in the first and second phases.

9. Barriers and opportunities for action

With CO₂ storage sites becoming operational and VCMs adopting full suites of relevant methodologies and tools for CCUS projects, there are no longer any fundamental barriers to pursuing crediting of Cement CCUS. Nonetheless, navigating the development of first-of-their-kind carbon projects requires addressing three barriers: a) clarity as to the eligibility of transboundary projects under the Swiss (inland) compensation system, b) international accounting of results and – linked to this – the question of whether an ITMO transaction is required to transfer credits to Switzerland, and c) clear arrangements among the partners to clarify ownership and accrual of carbon credits, as well as the ensuing sharing of the revenue among the many partners involved.

9.1 Request clarification of eligibility of transboundary projects for Swiss inland compensation

The implications of the question of where CCUS mitigation results are occurring extend far beyond international accounting rules and pertain even to whether an activity involving capture in Switzerland with storage abroad could principally be considered eligible under the Swiss compensation instrument. The question is whether capture by a Swiss entity would constitute the result having occurred in Switzerland, in which case the activity outlined here could be eligible as a domestic compensation project under the Swiss CO₂ law.

Alternatively, if the capture is considered a result that has been achieved abroad, then it could be purchased as an ITMO and used towards the foreign credits part of the compensation obligation.

9.2 International agreement to clarify where results occur

A precondition for carbon crediting in general – and especially if Article 6.2 transactions are envisaged (or A6.4M credits) – is clarity as to where the results are generated in the value chain. It is unclear to date whether a removal (or an emissions reduction) is accruing at the site of CO₂ capture or at the site of CO₂ storage. Unfortunately, this has never been legally clarified, and there are good arguments for both.

This influences whether the CCUS value chain from cement with capture in Switzerland, transport abroad and storage abroad would be considered as either a) achieving a mitigation result in Switzerland (upon capture) or b) achieving a mitigation result abroad (upon storage). In the former case, no international credit transaction would be needed for Switzerland to own the results. In the latter case, credits could be sold (as ITMOs under Article 6.2) to Switzerland, with corresponding adjustments abroad and in Switzerland. In our example, assuming Switzerland seeks to account for the mitigation results towards its NDC, in case a) Switzerland could directly report the results as a net reduction in emissions without international transfer of mitigation outcomes. This is because the capture – with the intent of storage – would be considered to achieve the mitigation result domestically in Switzerland, even when the physical storage takes place abroad.

‘Whether the rules are interpreted such that a removal result is achieved in the CO₂-capturing country or in the CO₂-storing country will determine whether or not an ITMO transaction would take place.’

While the Swiss Federal Government and its international counterpart involved in this transboundary value chain have engaged in an ongoing exchange to resolve this question, its

resolution is not yet clear. A resolution will eventually be required for transboundary cooperation, ideally in a manner that then becomes a standard international practice to ensure consistency. Ideally, the solution would then be finally affirmed in the IPCC inventory guidelines.

With this national accounting uncertainty, there is potential also for misunderstandings at the project level as to where the mitigation result is achieved along the CCUS value chain and who among those involved in the value chain is the rightful owner of credits being issued.

Given that in case a) there is no ITMO transaction involved, all carbon revenue for CCUS value-chain implementation will need to come from domestic policy incentivisation, or through the savings and opportunities for selling allowances, or from public procurement of VCM CCUS credits.

9.3 Institutional arrangements of ownership and revenue sharing

As described in Section 4, Step 0 of developing a cement-CCUS carbon project involves exploring and deciding on the most suitable institutional arrangements and drawing up the matching contractual arrangements, so that there is an effective project developer (either one of the value-chain partners, an aggregate entity comprising several partners, or a service-providing third party) and such that the requirements regarding reversal risk (as set out in the methodology and the reversal risk tool) are fulfilled. In our view, this will have to be the first step towards a carbon project based on cement CCUS.

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Blueprint 2b - International CCUS collaboration

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Blueprint 3:

Abroad CCUS value chain –

Biogas upgrading capture

with utilisation in concrete

DemoUpCARMA

Work Package 5: addressing policy, regulatory and acceptance challenges to enable CCUS deployment

Task 1: emissions accounting, reporting tools and climate finance mechanisms of negative emissions for national and transnational CCUS solutions

Zurich, 15 Dec 2023

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Table of contents

1. Summary	5
2. Background and objectives	7
2.1 Challenges for monetising CCUS activities	7
2.2 Blueprint focus	8
2.3 Objective	9
2.4 Materials and methods	10
3. Description of the value-chain use case	11
3.1 Description of the Scope of Activities	11
3.2 Technical feasibility and barriers	12
4. How to generate and monetise credits under the VCM	13
4.1 CCUS methodology beyond CCS+ Initiative	18
4.2 How to make VCM credits available for international transfer under Article 6.2	20
5. Swiss compensation scheme	21
5.1 Procedure towards carbon credits	22
5.2 Eligibility of the proposed CCUS project value chain	23
6. EU Carbon Removal Certification Framework	27
7. Potential (future) crediting and monetisation options	28
7.1 Article 6.4 – centralised Mechanism	28
7.2 ICAO – an emerging source of demand for credits	28
8. Barriers and opportunities for action	29
9. Bibliography	30

List of tables

Table 1: Project boundary 12

List of figures

Figure 1: Overview of the process for developing a biogas upgrading-CCUS carbon project of capture and utilisation abroad generating revenue from selling credits to Switzerland under the Paris Agreement Art. 6. 6

Figure 2: The value chain and monetisation option detailed in this blueprint 9

Figure 3: Overview of the four possible avenues of monetising mitigation results examined in the four blueprints 10

Figure 4: Criteria relevant to the integrity of carbon credits – to be demonstrated transparently by the standard 13

Figure 5: CCUS Methodology, its modules for capture, transport and utilisation and accompanying tool applicable in this blueprint 14

Figure 6: The carbon project cycle from idea to issuance of credits 16

Figure 7: The core elements of a project design document (PDD) 16

Figure 8: Swiss compensation scheme procedure 22

1. Summary

This blueprint explains how to generate and transfer carbon credits from a European biogas upgrading plant with carbon dioxide (CO₂) capture, utilisation and storage within the European Economic Area (EEA). It considers CO₂ capture at a biogas upgrading plant located in the EEA and CO₂ utilisation (with permanent storage) also in the EEA followed by a transfer of mitigation outcomes to Switzerland.

This document is part of a suite of four blueprints produced under the DemoUpCARMA project to aid the monetisation and scaling of carbon capture, utilisation and storage (CCUS)¹ applications in Switzerland under voluntary and compliance markets, both domestic and international. The blueprints collectively assess the following market cases:

- certificate sales via the voluntary carbon market (VCM)
- domestic compensation instrument under the Swiss compliance market
- international transfer of mitigation outcomes achieved abroad
- emissions trading systems (ETs)

and the following CCUS applications:

- CO₂ capture from a biogas upgrade plant, a WtE plant and a cement plant
- CO₂ transportation via trucks, rail, ships and barges
- CO₂ storage in concrete, subsurface supercritical CO₂ storage and subsurface mineralisation.

To help project developers in their quest to monetise – and thereby enable – CCUS adoption, each blueprint presents:

- an overview of challenges for the monetisation of CCUS activities
- monetisation options for CCUS in voluntary and compliance markets
- step-by-step guidance to generate credits
- considerations for the monetisation of credits
- barriers and opportunities for action

This particular blueprint explains the specific steps needed, the implications of various crediting systems, and opportunities for immediate action towards crediting and monetising mitigation results from a CCUS value chain consisting of:

- CO₂ capture from a biogas upgrading plant in the EEA
- CO₂ transportation via trucks, rail, ships and barges within the EEA
- CO₂ utilisation achieving permanent storage in concrete mineralization in an EEA country.

It guides through the process to monetise such a CCUS activity (Figure 1), from establishing a partnership along the CCUS value chain to selling and sharing the revenue from the carbon credits generated.

¹ This report, exclusively uses the term carbon capture, utilisation and storage (CCUS) to cover any type of activities ranging from carbon capture and storage in geological formations to carbon capture, utilisation and storage in durable products resulting in long-term storage.

Blueprint 3 – Abroad CCUS value chain



Figure 1: Overview of the process for developing a biogas upgrading-CCUS carbon project of capture and utilisation abroad generating revenue from selling credits to Switzerland under the Paris Agreement Art. 6.

(Source: Authors, 2023)

Carbon credits can provide a revenue stream to cover the additional cost of implementing CCUS technologies in the cement sector beyond savings incurred by their compliance with an Emissions Trading System (ETS). Generating the carbon credits, however, is not straightforward. It involves complex procedures to ensure a high-quality standard and environmental integrity in the quantification and certification of emission reductions or removals through CCUS activities.

Used as a companion to formal documents setting out requirements and processes, this blueprint helps anticipate the main challenges for monetising CCUS from a European biogas upgrading CO₂ source involving a transfer of mitigation outcomes to Switzerland as per the provisions of the Paris Agreement (Article 6). It contains a step-by-step guide to submitting a project to a voluntary carbon market standard for demonstrating compliance with the standards' requirements and it explains the additional requirements flowing from the Paris Agreement. Key challenges even before submitting a project are explained, such as defining which entity (among many involved along the value-chain) will be the project proponent to whom credits will accrue and how to arrange for the appropriate sharing of carbon credit revenues among value-chain partners. With an example, the blueprint illustrates how to describe the project scope, i.e., how to determine the project boundaries in time and space, and the suitability of the activity with carbon accounting methodologies. This document discusses the considerations and requirements for project development within the VCM. These aspects are systematically addressed in a designated Project Design Document (PDD). Under the framework of the Swiss compensation scheme, a corresponding document encompasses similar key topics such as the activity outline, baseline, and monitoring methodology. Complying with these requirements is crucial for meeting the Swiss compensation or VCM criteria and, more importantly, to ensuring a high-quality standard and high environmental integrity of the mitigation credits.

The blueprint, furthermore, provides guidance to navigate the evolving and increasingly complex carbon markets regarding international transfers to other countries following UN requirements for ensuring eligibility for such compliance markets that may promise to reap premium prices. For this, the blueprint explains key considerations of possible developments regarding compliance markets, notably the potential to generate credits under Paris Agreement Article 6.2 and the outlook to utilising the more formalised Article 6.4 to potentially achieve an even greater range of international demand for high-quality credits. Article 6 transfers that help ambitious countries like Switzerland attain mitigation targets – of the administration itself or of industries – thus provide additional opportunities for monetising CCUS activities – with an expectation of premium prices compared to purely voluntary markets. The blueprint outlines expectations of market dynamics ranging from voluntary and compliance markets to empower biogas upgrading actors (predominantly in the liquid waste sector) seeking to get into CCUS leverage carbon markets to achieve and monetize removal results.

2. Background and objectives

Developing a CCUS industry is challenging: multiple interlinked sectors and actors need to cooperate based on the shared interest in generating revenue related to climate change mitigation results. This requires creating an ecosystem of compatible interfacing logistical, technological and contractual pieces working cooperatively across a significant number of private-sector actors and in compliance with carbon market rules, while also ensuring compliance with national accounting in multiple countries. Despite advancements in pilot value chains funded by subsidies or induced by regulatory obligations, transitioning to a scalable business model reliant on carbon revenue or incentives from emissions trading remains challenging.

Currently, there are limited robust standards for tracking mitigation results from CCUS, despite relying on such results towards medium- to long-term mitigation goals. While initial CCUS pilot projects have accessed funds, scalable long-term funding for CCUS with clear climate benefits remains elusive. Effective climate action thus demands leveraging voluntary carbon markets (VCMs) to swiftly unlock revenue and draw lessons learned for regulatory approaches, many of which appear set to adopt key structures and methodologies from the first-mover VCM.

CCUS activities involve multiple sectors, sparking concerns of power disparities between highly capitalised established oil and gas companies (delivering underground carbon dioxide (CO₂) storage) and much smaller and novel carbon capture technology providers. This requires attention to ensure fair sharing of carbon revenue among partners.

2.1 Challenges for monetising CCUS activities

This blueprint addresses two challenges:

- 1) the lack of carbon market methodologies for tracking mitigation results from CCUS, and
- 2) the lack of clarity on accounting, responsibilities and ownership in carbon market projects within the complexity of CCUS hubs and clusters.

Need for a cohesive ensemble of carbon-tracking methodologies

The absence of a unified carbon accounting methodology has hindered CCUS projects from accessing carbon markets as a source of revenue. Traditional methodologies have been narrow, focusing on specific project chains rather than the comprehensive industrial ecosystem needed for effective carbon management. This fragmentation has hampered the generation of reliable credits from CCUS projects, especially those in larger interconnected systems. However, recent efforts, led by the CCS+ industry consortium in collaboration with Verra (associated with the Verified Carbon Standard (VCS)), aim to develop a comprehensive suite of methodology modules to address this gap.

The CCS+ Initiative introduces an advanced carbon accounting system for varied CCUS projects, using a modular approach for activities across capture, transport, utilisation and storage. A 'plug-and-play' system recognises shared infrastructures across CCUS technologies, enhancing adaptability to fit the numerous possible combinations across multiple hubs and clusters. The carbon accounting landscape had long been fragmented and lacked consistency across the emerging CCUS ecosystem. Though Verra and the Gold Standard have made progress, these standards would benefit from more stringent overall oversight to ensure long-term credibility via a coherent carbon accounting framework that also conforms with evolving formal accounting rules under the Paris Agreement. High-quality, evolving methodologies can ensure transparency.

Blueprint 3 – Abroad CCUS value chain

Adopting stringent, up-to-date standards can streamline quality assurance, reducing costs and increasing efficiency throughout CCUS value chains. While this blueprint primarily emphasises the carbon accounting landscape within the VCS, Section 4.1 offers an overview of additional carbon standards that assist early movers in securing revenue within the VCM.

Need for disambiguation of accounting, responsibilities and ownership

CCUS activities can achieve two different types of results, which need to be clearly differentiated depending on the source of carbon: reductions in emissions in the case of fossil carbon and removals of CO₂ in the case of biogenic carbon, which need to be transparently tracked and communicated. Other CCUS-specific ambiguities, particularly for CO₂ transport across national borders, can create confusion regarding responsibilities that need to be clarified by private contracts among various partners along the value chain. As a result, the private sector faces ambiguities concerning ownership, liability and carbon-revenue accrual. Navigating these challenges requires clarification of rules at the international level (including regarding national greenhouse gas (GHG) inventories). It also requires consideration of technical and institutional aspects, such as needing to ensure that project owners have control over the durability of storage. Lacking clarity regarding project ownership and liability as well as the respective contractual assurance can become problematic in case of leakage, or when regulations and carbon market rules evolve. Identifying key stakeholders and creating clear arrangements are vital and need to draw from best practices and existing guidelines to maximise compatibility across multiple storage hubs and clusters of emission sources.

2.2 Blueprint focus

The focus of this blueprint is generating carbon credits from a biogas upgrading plant with carbon capture, transport and storage abroad under the VCM standard VCS followed by a transfer of the mitigation outcomes per the Paris Agreements' Article 6 (see Figure 2).

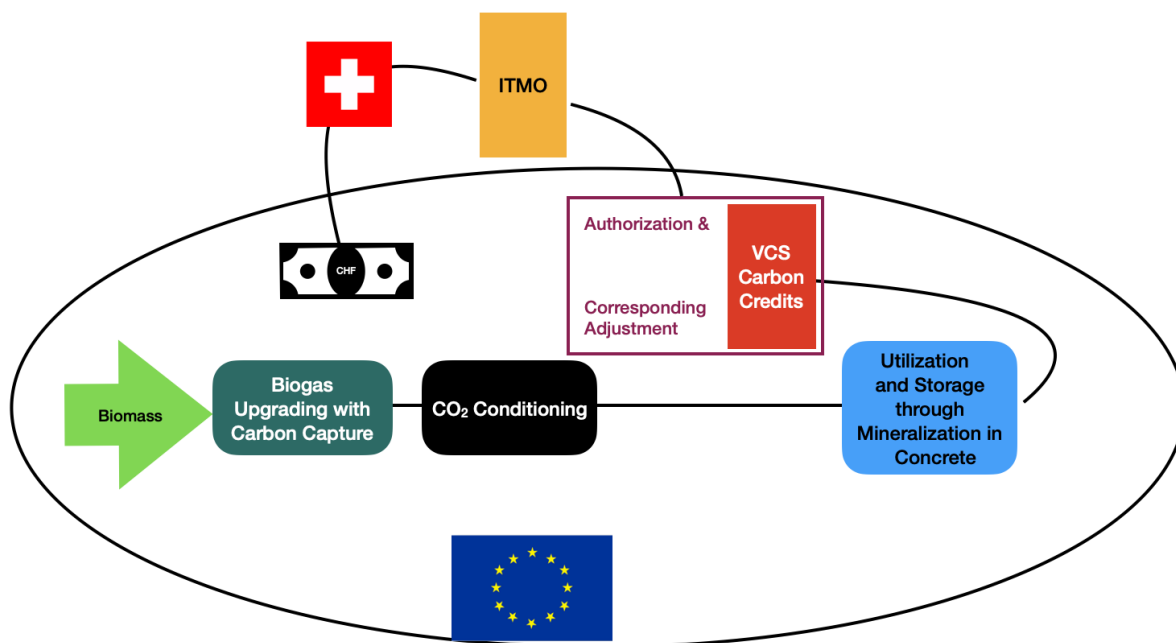


Figure 2: The value chain and monetisation option detailed in this blueprint

(Source: Authors, 2023)

2.3 Objective

The goal of this blueprint is to answer:

‘How can a European biogas upgrading-CCUS project developer generate revenue based on the mitigation results of their activities in carbon markets and beyond?’

The VCM is the starting point as this is what the underlying ensemble of methodologies has been designed for. As existing standards do not yet provide robust methodologies for certifying complex CCUS activities, the blueprints build on a state-of-the-art carbon accounting infrastructure currently under development by the CCS+ Initiative for the VCS. The CCS+ methodologies provide a high-quality standard for the responsible adoption of CCUS activities (CCS+ Initiative, 2023). Using such a strict standard enables project developers to fulfil the transparency and environmental integrity requirements of voluntary or compliance standards that may emerge in the future across jurisdictions around the world. This blueprint shows the process to generate and sell carbon credits under the VCM, including guidance to define the project design document (PDD), which builds on methodologies’ robust technical considerations. In a second step, the blueprint also shows how a largely identical approach may allow the use of methodologies for tracking emission reductions and CO₂-removal results beyond the use for selling voluntary credits in other carbon-crediting and results-based incentive systems. It shows the opportunities, challenges and pitfalls of each of these avenues to carbon revenue.

This document seeks to clarify and disentangle these issues, and to offer guidance to private-sector project developers by explaining the development and formalisation of such a carbon project (see Section 3).

While the blueprint starts with explaining the approach under the VCM and how voluntary credits can be used for transfers under the Paris Agreement Article 6.2 (upon authorisation and corresponding

Blueprint 3 – Abroad CCUS value chain

adjustments; see the second option in Figure 3), it also points to the generation of credits under the UN A6.4M. It furthermore outlines the potential consequences, should the entities conducting biomass upgrading ever become subject to the European Emissions Trading System (ETS).

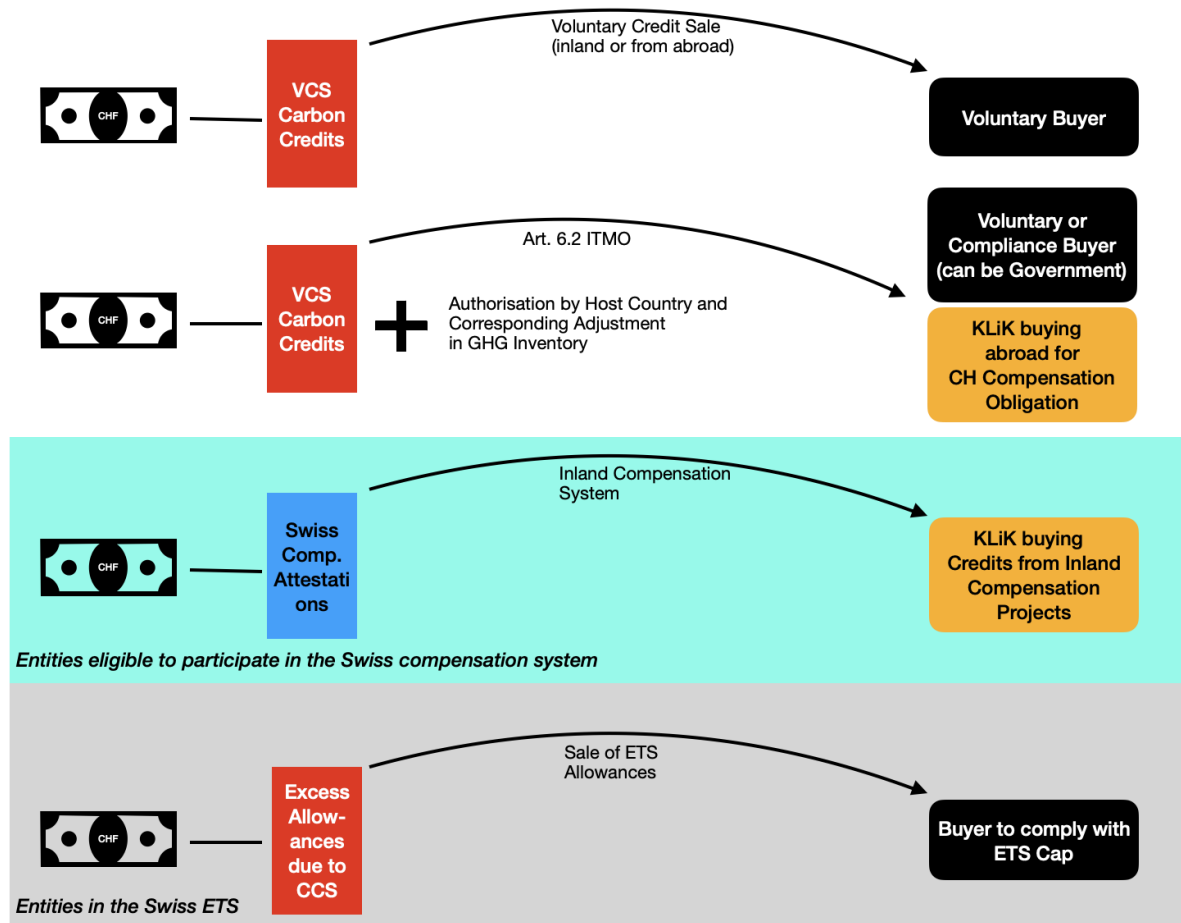


Figure 3: Overview of the four possible avenues of monetising mitigation results examined in the four blueprints; this blueprints' focus is on the second one.

(Source: Authors, 2023)

2.4 Materials and methods

This blueprint draws primarily on the applicable baseline, and monitoring, reporting and verification (MRV) methodology, modules and tools. These were developed by Perspectives and South Pole with input from stakeholders in CCS+ and DemoUpCARMA. Secondly, blueprints and methodologies are informed by provisions in the contexts of GHG inventories, EU storage rules and EU carbon certification considerations, as well as the UNFCCC Article 6. Pertinent information on these matters is incorporated in condensed form to offer a cohesive guide to approaching international cooperation on transboundary CCUS value chains designed for maximum compatibility with these policy contexts, for the case of a European biogas upgrading plant and CO₂ utilisation and storage in the EEA.

3. Description of the value-chain use case

CCUS projects involve the capture of carbon dioxide (CO₂) from a point source or directly from the atmosphere. The captured CO₂ is typically compressed and transported by pipeline, ship, rail, or truck to be injected into deep geological formations (e.g., deep saline aquifers, depleted oil and gas reservoirs, or reactive rock formations). Alternatively, CO₂ can be used for long-term storage in building aggregates such as concrete. The latter is the focus of this blueprint as outlined in the following.

3.1 Description of the Scope of Activities

The value-chain case example outlined by this blueprint includes the collaboration between entities in the EEA capturing CO₂ at a biogas-upgrading facility, the transport of CO₂ in one or several countries in the EEA via trucks, and storage through the durable utilisation (mineralization) of CO₂ in concrete. The transport distance of such a value chain is likely to be much shorter than in other cases, given that construction material processing sites are (presently) much more ubiquitous than geological CO₂ storage sites.

A key aspect of developing and describing a carbon project (as shown in section 4) is determining its boundaries in time and space. The following table outlines how this could look like in the case examined here.

Table 1: Project boundary

Geographical boundary	Refers to the location of the project activities.	One or several countries in the EEA – spanning the processes of capture, transport and utilisation in concrete
Temporal boundary	Refers to the timeframe during which the project activities occur and impact GHG emissions.	The temporal boundary for this project type is unclear to date: it will be determined by the crediting period multiplied by the max. allowable renewal (in the final CCUS methodology). ²
GHG sources	All relevant sources of GHG emissions are identified and included within these boundaries.	Biogas upgrading facility, conditioning leakage, transport leakage, energy required for conditioning, transport, and storage, cement plant leakage

² In case of projects involving geological storage of CO₂, the maximum project duration under the VCS is 42 years (7 years crediting period, renewed for up to 5 times). The higher (chemical) durability of binding CO₂ in cement may result in even more favourable provisions in the CCUS methodology.

Secondary effects³	The project boundary also considers secondary effects related to the project.	Secondary effects could include emissions associated with a relative increase in conventional, less expensive, concrete production

(Source: Authors, 2023)

One example of a biogenic source is the liquid waste sector. Biomass upgrading on liquid waste treatment plants is a relatively small CO₂ point source, which tends to be spread out regionally given the need for local/municipal wastewater treatment. The liquid waste sector deals with a magnitude of hundreds of thousands of tCO₂, which – compared to other emissions sources e.g. cement or even the waste incineration sector – are relatively small emission sources. Furthermore, they represent a purely biogenic CO₂ source. Given European climate neutrality ambitions and the growing pressure to deliver carbon dioxide removal results, biogenic sources of CO₂ are expected to play an ever-increasing role. Here, the liquid waste sector and other biogenic sources such as biogas plants from digestion may be targeted specifically for CCUS to deliver carbon dioxide removal results.

3.2 Technical feasibility and barriers

The separation of CO₂ from a biogas mixture using membranes as well as the liquefaction of CO₂ are well-established processes that are widely used in the biogas and chemical industries. The technology to store CO₂ in concrete for construction material production, which has now been applied and proven with various partners in the cement sector and at various sites is maturing rapidly. Operationalisation challenges still occur, which – though not individually critical – can cumulatively complicate the smooth implementation and management of such activities especially when involving new partners and especially when it requires the adoption of new standards for the introduction of new products in the construction industry.

As a project taking place purely within the EEA, this type of activity – if done within a single country – also avoids the complications related to transboundary transport of CO₂ regarding accounting and ownership of credits. And given that solely biogenic sources of CO₂ are involved, there is no need to differentiate results into removals and emissions reductions (in contrast to e.g. the case of municipal solid waste incineration). This also means that none of the results are presently covered by Emissions Trading Systems, which also simplifies the process for crediting – though this could potentially change in the future.

³ Most methodologies foresee a materiality threshold that allows cutting off secondary effects of irrelevant size to avoid unnecessary complexity.

4. How to generate and monetise credits under the VCM

The VCM has grown in recent years and offers a meaningful source of revenue for climate mitigation results. VCM involves the sale of carbon credits, which can be bought for voluntary offsetting, voluntary (non-offsetting) mitigation contributions, or in some cases also for offsetting obligations (if additional requirements are met). Credits are issued through a formal process by standards such as the VCS can be traded either directly or through intermediaries. Though often used to make carbon neutrality claims, they increasingly serve more broadly as a means to track mitigation results in a consistent and verifiable manner.

The process of generating carbon credits essentially serves to transparently demonstrate that the conditions for integrity are met by the proposed activity. The integrity of carbon credits requires transparently meeting the seven factors shown in Figure 4.

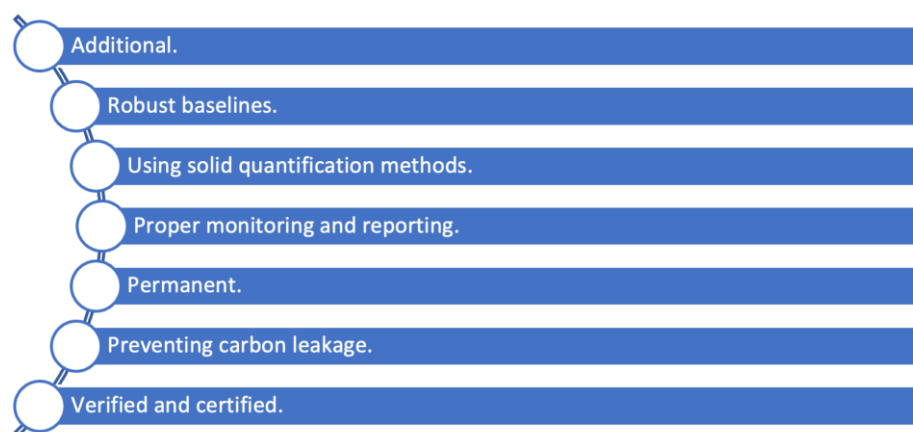


Figure 4: Criteria relevant to the integrity of carbon credits – to be demonstrated transparently by the standard

(Source: Authors, 2023)

Methodologies are vital for quantifying greenhouse gas benefits, generating credits and monetising them in the VCM. These methodologies are regularly updated for accuracy and relevance. For this, specific methodologies have been developed under a voluntary carbon market standard – in our case, under the Verified Carbon Standard (VCS). For the case examined here, the Methodology for Carbon Capture and Utilisation and Storage is relevant along with the following modules: CO₂ capture from biogenic sources, Consolidated Module for CO₂ Transport, and utilisation of CO₂ in concrete.

Besides the overarching methodology and value-chain specific modules, the use of the tool for baseline quantification and allocation of project emissions in projects with VCS and non-VCS- CO₂ flows is further required, if the CO₂ captured in the biogas facility is mixed with CO₂ from other sources before being utilised in concrete (see Figure 5). This is needed to differentiate between the CO₂ from VCS and non-VCS project activities, as CO₂ leaving the project boundary (i.e. non-VCS CO₂) must be quantified and excluded from the project's emission reductions or removal results that may be credited in the VCS.

Blueprint 3 – Abroad CCUS value chain

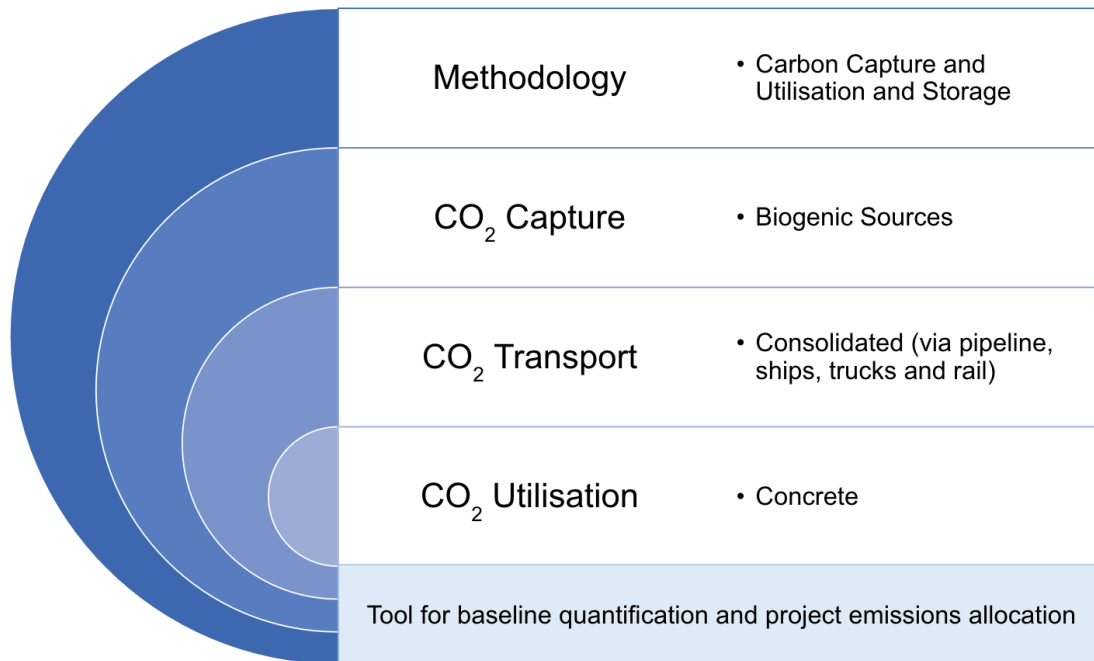


Figure 5: CCUS Methodology, its modules for capture, transport and utilisation and accompanying tool applicable in this blueprint

Source: Authors, 2023

Examining early the information required – by the methodology and tools – from the prospective project and the various partners involved, will make it easier to prepare the necessary institutional and contractual arrangements for partners along the value chain as outlined in the following step 0.

Step 0: Preparations for a transboundary CCUS value chain

The complexity of CCUS value chains requires a number of measures even before formally starting the carbon project development under a specific standard. This notably includes figuring out the most suitable institutional arrangements along the value chain, including signing agreements to meet VCS requirements. Important requirements to consider at the outset (for all projects involving geological storage of CO₂) are outlined in the ‘Geologic Carbon Storage (GCS) Requirements’ (Verra, 2023b). The GCS is the key tool for ensuring inter alia that the entity receiving credits is also held responsible should reversal occur. It offers an important basis also to consider the question of who is going to be the project proponent; it can be preferable that the storage provider is also the project proponent, or that they are tied contractually to ensure the durability of storage and dealing with reversals.

Alternative modes of collaboration should also be considered. For example, instead of choosing one of the partners in the value chain to act as the project proponent and project developer, partners could form a legal entity for the purpose of developing the carbon project. A third model is that an outsider–professional project developer acts as the project developer on behalf of the value-chain

Blueprint 3 – Abroad CCUS value chain

partners, which offers the advantage that in some cases such a project developer takes on the financial cost and risk of the project development itself.

Another important tool that may be considered at the outset is the Non-Permanence Risk Tool (NPRT)(Verra, 2023a), which offers an evaluation of reversal risk. Early consideration of reversal risk may help structure contractual arrangements for dealing with the consequences of reversals among value-chain partners should it occur later on (e.g. to avoid unduly placing the financial burden on certain partners or failing to ensure appropriate incentives for the partner responsible for storage).

Furthermore, decisions need to be taken at the outset regarding the envisaged accrual and use of credits inter alia to prevent double-counting issues. This includes whether the results are to accrue under the domestic Swiss compensation system as a so-called '*Innlandszertifikat*', or whether – if the results accrue abroad – an international transfer (back to Switzerland) is envisaged as an Article 6.2 internationally transferred mitigation outcome (ITMO) (requiring corresponding adjustment as described in Section 5). Similarly, it may be worth considering whether the share of removals may in the results be marketed separately (targeting buyers who are willing to pay a premium for innovative removal credits) and for this, a clear distinction between both types of results is required (using the corresponding tool).

For any ambiguities that imply decisions by governments (potentially in bilateral state contracts), the resolution should be proactively sought from the respective authorities. This concerns: a) cases where there is ambiguity as to where results occur, b) whether consequently an Article 6.2 transaction is envisaged and c) whether the activity may be eligible for the Swiss domestic compensation instrument as either an inland-compensation project or as a foreign-compensation project. To undertake the first transboundary CCUS carbon credit project will require time to develop a shared understanding as a basis for formal collaboration contracts. A common understanding of the technical, legal and contractual requirements and associated responsibilities is needed to then translate into appropriate contractual arrangements as the basis for collaboration.

The following Steps 1–6 are part of the so-called 'carbon project cycle' exemplified hereafter for the VCS.

Step 1: Activity design

The process, as demonstrated in the example of the VCS, is very similar in most standards and is often referred to as the 'carbon project cycle'. The key phases are shown in Figure 6. The process for carbon credit issuance typically begins with a PDD submission by the activity developer. This document outlines the activity, baseline and monitoring methodology. An independent third party validates the activity before registration. Once operational, the developer monitors and reports emissions reductions as per the PDD. The outcomes are then independently verified for carbon credit issuance.

Blueprint 3 – Abroad CCUS value chain



Figure 6: The carbon project cycle from idea to issuance of credits

(Source: Authors, 2023)

This is the most work-intensive phase for the project proponent. It culminates in the preparation of a Project Design Document (PDD), which captures all relevant information as required by the methodology (including for additionality demonstration, baseline identification and the monitoring plan). PDDs serve a key role up to validation as they demonstrate a proposed project's compliance with the conditions for integer carbon projects (see Figure 4). The PDD's core elements are shown in Figure 7.

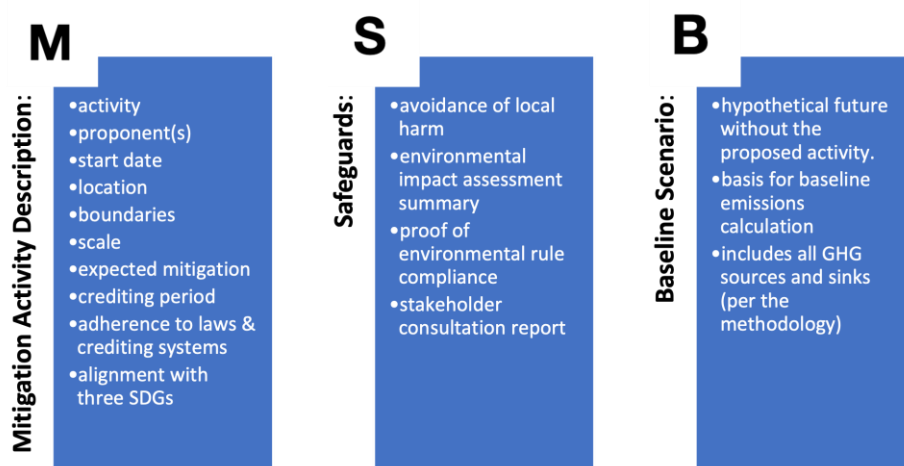


Figure 7: The core elements of a project design document (PDD)

(Source: Authors, 2023)

A central element in developing the PDD is the definition of the project boundaries, which is particularly challenging in the case of CCUS activities; while in the most simple case, the project comprises of a single capture, transport and storage facility, it is also possible that multiple capture facilities are included through a shared storage facility, or vice-versa that CO₂ captured from a single site is stored at multiple sites. For all these processes, the project boundary includes electricity, fuel, and material inputs as well as their associated emissions – including venting and fugitives.

Another key piece is the setting of the baseline, which in the case of adding carbon capture (for storage) to an existing biogas upgrading plant essentially assumes a continuation of CO₂ emissions

Blueprint 3 – Abroad CCUS value chain

into the atmosphere. The baseline emissions can be determined by the amount of CO₂ mineralised into concrete.

As part of the PDD, the proponent will need to demonstrate additionality. Additionality is present if, without the incentives from carbon credits, the mitigation activity would not occur, and thus no emissions reductions or removals would be realised. Additionality is crucial to maintain environmental integrity and ensure efficient use of funds for climate change mitigation. Its proof needs to be provided following the guidance of the CCUS methodology in three steps, based on investment analysis: 1) Regulatory Surplus, 2) Implementation Barrier and 3) Common Practice – i.e. to demonstrate that the project is delivering mitigation beyond regulatory requirements, that a financial barrier is in place and that the activity is not (yet) common practice. Projects that pass all three of these steps are considered additional. For a pre-defined set of carbon-dioxide removal (CDR) technologies, the CCS+ Initiative aims to develop an alternative approach to demonstrating additionality. While a demonstration of the regulatory surplus will remain in any case, an alternative approach to the investment analysis, e.g. through a positive list, will be elaborated in the future.

In the PDD, the proponent will also need to present the monitoring plan. This plan anticipates the monitoring activities that will be required during the monitoring period. It indicates the physical equipment to be used (e.g. meters), and the responsibilities and processes for collecting, processing and reporting data, as required by the methodology. It defines the parameters that need to be measured, their accuracy and the measurement frequency.

Step 2: Validation

Upon submission of a PDD by the project proponent to the standard body, the validation process starts. It involves a third-party validation/verification body (VVB) – approved by the carbon credit standard – which independently checks if the proposed project meets the standard's requirements. The first step of validation is a public review for about a month, followed by desk evaluation and then a site visit by the VVB. Based on these inputs, the VVB examines the accuracy of claims in the PDD, and either recommends the project for registration or suggests changes before it can be registered.

Step 3: Registration

Upon validation, the carbon standard does a completeness check and registers the project in its registry. This will enable the project owner to generate carbon credits for an initial period, called the crediting period. The length of the crediting period is set by the standard and can vary for different project types. The crediting period for this project type is unclear to date: it will be determined by the crediting period multiplied by the max. allowable renewal (in the final CCUS methodology).

Step 4: Monitoring and reporting

Upon registration and the start of activities, the MRV of results starts. A monitoring report is prepared following the data and information requirements set out in the latest VCS requirements for geological carbon storage and the respective methodology and modules. If a loss of containment occurs, the procedures outlined in the VCS Program (Verra, 2023c), the GCS requirements and the GCS NPRT shall apply.

Step 5: Verification of results

The report is verified by a VVB and the project proponent can then file a credit issuance request to the carbon standard.

Step 6: Issuance of credits

If everything is in order, credits will be issued in the registry and transferred to the proponent's account. Active credits can then be sold to gain revenue.

Step 7: Sale of credits

There are two key types of buyers: intermediaries/market aggregators, and end users. The latter include individuals, businesses and governments, but for project proponents with a small portfolio, they will be difficult to reach. Intermediaries include brokers, traders and exchanges (e.g. Carbon Trade Exchange (CTX), the CME Group and Xpansiv), which tend to charge a fee ranging from 5% to 20%. The sale can happen either before credit issuance (via an Emission Reduction Purchase Agreement (ERPA)) or after issuance. ERPAs under the VCS follow a template (IETA, 2023), which establishes roles, rights and responsibilities regarding project risks besides price, amount and credit delivery timeline. Another option for project initiators is partnering with activity development partners, who accompany the project from its inception to issuance and in some cases front the associated expenses to in turn be remunerated with a portion of credits generated later.

Removal-based credits are expected to fetch a higher price than those representing emission reductions, especially those that can clearly demonstrate durable storage.

4.1 CCUS methodology beyond CCS+ Initiative

Unlike other alternatives, the CCS+ carbon accounting infrastructure offers a unique modular 'plug-and-play' system approach to properly incorporate a wide set of possible project configurations. The aim is to include the majority of the current CCUS activities, and by addressing each technology type separately, future solutions can be effectively integrated into the infrastructure.

Today technology and industry players in the CCUS space offer a wide range of carbon capture, transport, utilisation and/or storage solutions. All these solutions need to be addressed and accounted for in their unique way. Methodologies are usually focused on specific technologies or define a set of eligible activities. This potentially leads to mitigation activities from one emitting sector not being eligible under the same accounting methodology due to different use of technologies or project activities. This is where the CCS+ initiative accounting structure would come into play.

In addition to the methodologies developed by the CCS+ Initiative under the VCS, various other carbon standards are actively working on the development of robust accounting methodologies to tackle the diverse and complex topic of CCUS. This section offers an overview of methodologies available or under development, specifically concentrating on carbon standards endorsed by the International Carbon Reduction and Offset Alliance (ICROA)⁴.

In this blueprint, the project value chain deals with the capturing of biogenic CO₂ from a biogas upgrading facility with subsequent transport via trucks and long-term storage in concrete.

⁴ ICROA collaborates with various stakeholders in the voluntary carbon market, including project developers, carbon standards, and businesses seeking to offset their carbon emissions, promoting high standards and best practices in the voluntary carbon market. It ensures measurable, permanent, additional and independently verified emissions reductions.

Blueprint 3 – Abroad CCUS value chain

Depending on the specific technologies used in the project design, these activities could potentially be covered by methodologies published by the Gold Standard (GS), Puro.earth (Puro), and the VCS⁵.

Gold Standard (GS)

Often considered the ‘gold standard’ of carbon standards, GS favours high-hanging fruits in the VCM and is known for having robust stakeholder consultation, safeguarding and sustainable development goal (SDG) requirements. The methodology is applicable for project activities aiming at sequestering CO₂ in demolished concrete aggregates (Gold Standard, 2022). It involves the capturing of biogenic CO₂ from direct air capture (DAC) or a diverse range of biogenic sources including the separation of CO₂ and methane at a biogas upgrading facility. The means of CO₂ transport is limited to trucks. The final sequestration of CO₂ is tied to a specific direct or indirect mineral carbonation technology. While GS covers the project value chain of this blueprint, it has to be seen, if the potential project developer can meet the technological requirements as described in the methodology. Here, a detailed assessment of the specific project design would need to be done.

Puro.earth (Puro)

Puro is focussed solely on removals, technological/industrial or nature-based. Its methodology addresses CO₂ removal through the chemical binding of CO₂ in carbonated materials (Puro.earth, 2022). The sequestration and storage of CO₂ sourced from DAC or any other biogenic source is eligible in any solid material which includes metal carbonates such as CaCO₃ and MgCO₃. The methodology does not specify the mode of transport. With this broad approach to eligible project activities, Puro allows the majority of technological solutions and potential project developers to be eligible under their methodology. This is attractive to early movers and providers of novel technologies as they can develop their projects and monetise their activities under the VCM.

Verified Carbon Standard (VCS)

The VCS, as the world's most widely used GHG crediting program, has developed a CCUS methodology before the efforts undertaken by the CCS+ Initiative. This methodology focuses on CO₂ utilisation in concrete production (Verra, 2021). Unlike the other two methodologies, here the focus is on waste CO₂ which would have otherwise been emitted to the atmosphere and DAC. The CO₂ is not limited to a transport mode. CO₂ reductions are archived by sequestering waste CO₂ in their ready-mix concrete and further reducing emissions by requiring less cement during the production process. Similar to the GS methodology, a detailed assessment of the specific project design and technologies needs to be done, to evaluate its eligibility under the VCS methodology.

Generally speaking, all standards, which are discussed in this blueprint, follow the same goal of developing rules, requirements and procedures for the design, development, monitoring and reporting of carbon projects which then results in an emission reduction or removal. Yet, when examining individual technology groups and solutions in isolation, rather than considering the entire value chain as a whole, the CCS+ initiative can craft a more robust carbon accounting mechanism for diverse project value chains.

⁵ Not related to the CCS+ Initiative.

4.2 How to make VCM credits available for international transfer under Article 6.2

To make credits generated through the VCM available for purchase by other countries such as Switzerland, the project developer needs to anticipate and act on the provisions set out under the Paris Agreement Article 6. The Paris Agreement allows countries to cooperate to achieve their NDCs – based on the authorised transfer of ‘mitigation outcomes’ (so-called ITMOs). ITMOs can also be used towards obligations on international aviation under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

Authorisation as a precondition for ITMO transfer requires that the party from which the credits originate apply a so-called ‘corresponding adjustment’ (CA) to its GHG inventory. It is important to highlight that CAs do not alter the national GHG inventory but rather serve as adjustments to the emission balance, reflecting the emissions source under NDC targets. When a country uses the ITMO to achieve NDC targets, the buyer country also applies CA in its inventory. In most cases, ITMO transfer will rely on crediting via an established VCM standard, but countries can in principle also develop their own crediting systems if both buyer and seller countries agree on the requirements. Credits authorised as ITMOs have a broader demand base, including governments, airlines and voluntary buyers, and are likely to fetch a higher price. Credits without CA are increasingly seen as unfit for compensation and carbon neutrality claims, meaning that over time voluntary buyers will be willing to pay a premium once CA and ITMO transfers are operational at national and UN levels in one to two years.

Switzerland and other countries are already engaging in purchasing contracts with entities abroad – and with their respective governments – to determine quantities, conditions and responsibilities for carbon credit generation and ITMO transactions.

5. Swiss compensation scheme

The Swiss compensation scheme is driven by the mandate outlined in the country's CO₂ Act (Federal Assembly of the Swiss Confederation, 2011), which requires fossil-fuel importers to offset a specific portion of their emissions. To meet this legal obligation, the KliK Foundation acts as an intermediary, connecting fossil-fuel importers with emission-reduction projects⁶ that generate carbon credits. These carbon credits from the approved projects are sold to fossil-fuel importers to offset their carbon emissions. The compensation scheme distinguishes between domestic projects within Switzerland and those undertaken abroad. The compensation obligation is defined as a specific percentage of the overall emissions produced by the imported fuels, which have to be offset partially in Switzerland and internationally. For a more in-depth exploration of the Swiss domestic compensation scheme and further details on additional CCUS activity support funded by unused funds from KliK's predecessor, the Climate Cent ('Klimarappen') Foundation, please refer to a separate document developed under the DemoUpCARMA project (South Pole, 2023).

This chapter is dedicated to providing prospective CCUS project developers in the value chain outlined in this blueprint with insights into procedures for establishing a foreign CO₂ compensation project under the Swiss compliance scheme. The chapter describes aspects of project development, which share similarities with developments in the VCM. Nevertheless, within the compliance scheme, several processes and structures are different (e.g. relevant documents around the registration of a climate project). Under the VCM, a clear distinction is drawn between a methodology and a project development. While a methodology defines standardised rules for executing, monitoring and verifying emission reductions, ensuring consistency across projects, the PDD describes unique project-specifics that apply a methodology, detailing project specifics and serving as evidence for each individual carbon offset project. In the Swiss compensation market, these essential documents are combined into a joint project description and a monitoring plan. Nevertheless, they all include critical elements such as additionality, baseline definition, MRV processes, system boundaries, leakage and conservative CO₂ reduction quantifications. Unlike the VCM, where project proponents can potentially apply an existing standalone methodology to their project, Swiss compensation mechanisms require the development of all relevant documents for each project.

Another notable feature of the Swiss compliance scheme is the compensation obligation imposed on the KliK Foundation. Securing Swiss 'attestations,' hereafter referred to as carbon credits, is subject to negotiations with project developers. It is essential to recognize that buyers in the VCM may also become potential purchasers of these credits. Typically, project proponents engage in ongoing discussions with KliK throughout the registration process with FOEN. A process, detailed later in this chapter, such as the option to have a 'project outline' document evaluated by a third-party validator and verifier (VV), provides an initial estimate of certificate quantities and the project's likelihood of acceptance and registration. Early discussions will be relevant for financial assessments during project development.

The following chapters provide an overview of the registration process for the chosen CCUS project value chain, while also highlighting requirements and general principles. For an in-depth description, please refer to the document provided by FOEN (FOEN, 2022). The provided overview and information on the Swiss compensation scheme are extracted from the same document.

⁶ The Swiss compensation scheme allows the development of single projects or programs that group several activities with common purposes. For simplicity, this document only refers to projects.

5.1 Procedure towards carbon credits

In the Swiss compliance market, the procedure for generating carbon credits closely mirrors the carbon project cycle previously outlined for the VCM, as depicted in Figure 6. Figure 8 provides a visual representation of the application process (Steps 1 to 3), and the ongoing monitoring, verification and transfer of carbon credits (Steps 4 to 6). In addition to these six steps, the figure emphasises the various documents that require authorisation, validation or verification by the involved stakeholders. In our project example, these stakeholders include FOEN in Switzerland, a VV (a third-party validator, similar to a validation/verification body (VVB) in the VCM in Switzerland as the host country and all partner countries within the CCUS value chain.

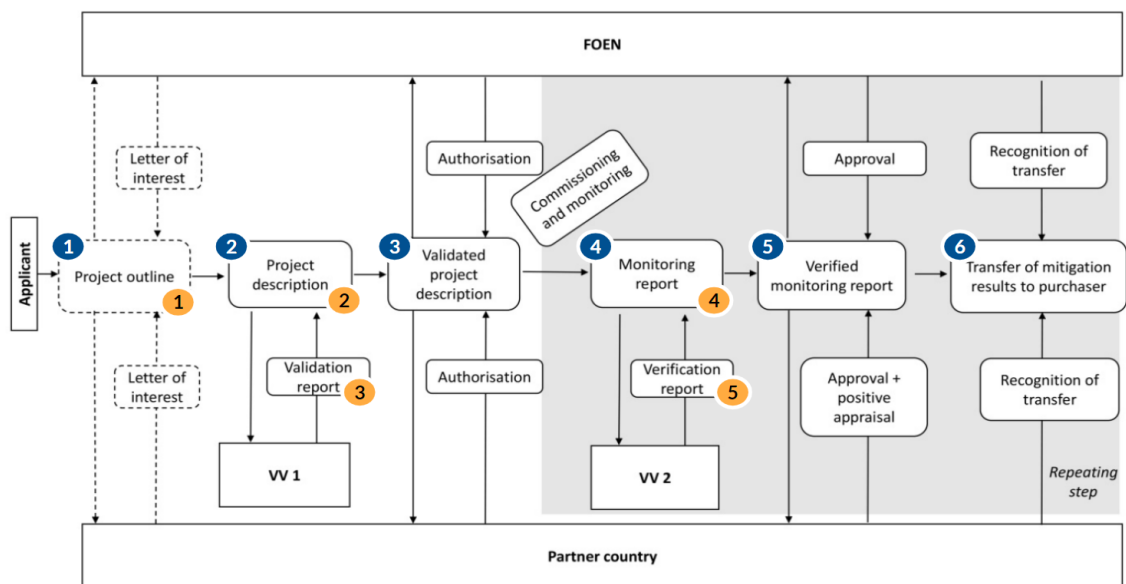


Figure 8: Swiss compensation scheme procedure (blue circles indicate carbon project cycle steps; orange circles indicate relevant project development documents necessary for application and ongoing monitoring, verification and credit issuing cycles)

(Source: adapted from FOEN, 2022)

Step 1: Project outline (optional)

In the first optional project outline, the developer can submit a project outline document to the FOEN and the partner country. This document serves as a preliminary assessment and a first eligibility judgement is assessed. Critical issues include additionality, differentiation from other climate policy instruments and preliminary calculation of expected emission reductions.

Step 2: Project description and validation

A detailed project description includes the following information such as: A detailed project description, an economic feasibility analysis, reference scenario development, differentiation from other climate policy instruments, a calculation method for determining emission reductions, a monitoring plan, and the validation report. The validation report is the revision of the project description by a FOEN-approved VV.

Step 3: Authorisation

After the VV approves the project description in a validation report, the project developer receives authorization from FOEN and the respective partner countries involved along the project value chain, the project is eligible to commence the annual, ongoing Monitoring, Reporting, and Verification (MRV) process.

Step 4: Monitoring

The project description defines the start date for monitoring emissions and the method for demonstrating emission reductions. Typically, monitoring begins when the project becomes operational. The monitoring report demonstrates the emission reduction according to the monitoring plan outlined in the project description for each year. The monitoring report has to be verified by the VV.

Step 5: Approval by FOEN and partner countries

The verified monitoring report must be approved by the FOEN and partner countries.

Step 6: Transfer of mitigation results (carbon credits)

Carbon credits are transferred to the KLIK Foundation.

5.2 Eligibility of the proposed CCUS project value chain

As of the revision to the CO₂ Ordinance in June 2022 (Federal Assembly of the Swiss Confederation, 2012), CCUS projects involving long-term storage in biological or geological formations, or non-organic building materials (e.g. concrete) have become eligible for the generation of carbon credits within the Swiss domestic compensation scheme.

All project developers need to draft a project description, which will be used to assess the eligibility of the proposed project (Step 2 of the carbon project cycle). Issues relevant to this blueprint's value chain are discussed in the following.

Compliance with applicable legal provisions, differentiation from other climate policy instruments and avoidance of double-counting

Similar to projects in the VCM, this project must demonstrate compliance with other relevant legal provisions, differentiate from other climate policy instruments and avoid double counting. For instance, if the EU ETS were to include biogenic CO₂ emissions, the project activities would no longer be eligible under the Swiss compensation scheme. Currently, however, the proposed activities with biogenic CO₂ stored in concrete or concrete-related products such as aggregates would be eligible. It is uncertain whether the activities described in this blueprint would be attributed to the cement industry (which stores the CO₂) or the industry from which CO₂ is captured (for example liquid waste). This does, however, not necessarily affect eligibility, given that in the present form of the ETS, biogenic CO₂ is not included in the ETS (and therefore does not hinder crediting under the Swiss compensation scheme).

However, some companies in this space claim that CO₂ utilisation in concrete or a concrete-related product has a secondary substitution effect (reducing the need for the use of clinker in concrete production). This substitution effect could not be credited to the Swiss compensation scheme as the associated CO₂ emissions are covered by the ETS.

Blueprint 3 – Abroad CCUS value chain

To demonstrate compliance with the legal provisions of countries in which project activities are taking place, bilateral climate agreements⁷ are a necessary precondition to carrying out projects in foreign countries under the Swiss compensation scheme.

Permanence of carbon storage

Under the Swiss compensation scheme, stated in the CO₂ Ordinance (Art. 5 para. 2), projects need to demonstrate a CO₂ storage of at least 30 years, regardless of the project duration and including after completion of the project. This requirement can be met by project activities dealing with CO₂ utilisation and storage in concrete structures. Requirements for concrete structures usually range from 50 to 100 years (Müller et al., 2014) which normally range. Additionally, a Non-Permanence Risk Tool offers an evaluation of reversal risk (Verra, 2023a). This tool could be consulted to assess the permanence of certain project activities in the CCUS scope. However, this risk tool is currently only available for CCS projects, mineralisation in products, such as the described activities in this blueprint is still to be developed.

Demonstration of additionality

Additionality under the Swiss compensation scheme is demonstrated by providing evidence that the project would not be economically viable without the revenue from the carbon credits for the entire duration of the project^{8,9}.

This can be shown in one of the following ways:

- Simple cost analysis: If a project has no other revenue streams apart from the sales of the carbon credits, a simple cost analysis is used. Demonstrating that the project is not profitable and less viable than the most likely alternative scenario.
- Investment comparison analysis or benchmark analysis: Key financial indicators such as NPV or IRR are compared between the project scenario and the alternative scenarios. An additional sensitivity analysis is done, to demonstrate the financial assessment is robust when assumptions are adjusted.

To analyse the economic viability, all costs and income streams need to be compared between the reference scenario and the project scenario. In our case, the substantial investment cost for a capture unit and a utilisation plant and ongoing operational cost for both activities would need to be covered by the revenue by sales of concrete products alone, to deem the project as ineligible under the Swiss compensation scheme. Considering the reference scenario, in which neither CO₂ capture nor transport and utilisation in concrete takes place, the project scenario is very unlikely to be financially viable.

In addition to the economic analysis described above, the project developer must show that the project is not common practice. CO₂ capture followed by mineralisation in concrete is still a

⁷ A bilateral climate agreement that governs cooperation between two countries and establishes the legal framework for the implementation of climate mitigation activities. Including a clear delimitation from partner countries nationally determined contribution (NDC). A list of bilateral agreements between Switzerland and foreign countries can be found on the FOEN website (FOEN, 2023).

⁸ It is essential to include all types and sources of revenue. These include development assistance from donors, other climate finance mechanisms, public funding or other non-refundable payments.

⁹ The economic feasibility analysis is based on UNFCCC's Tool for the demonstration and assessment of additionality (UNFCCC, 2012).

Blueprint 3 – Abroad CCUS value chain

relatively rare practice. The significant initial capital required for CO₂ capture and mineralisation facilities presents a substantial barrier. Further research, development, and financial support are needed for the successful integration of this technology.

Possible project duration

The Swiss compensation scheme, which obligates fuel importers to offset a portion of their emissions, was established based on the CO₂ Act. This legislative framework is in force until the end of 2030. However, without subsequent follow-up legislation, fuel importers will no longer be bound to offset their emissions from 2031 onward. Consequently, project developers are left with no assurance that this revenue stream will continue to exist. The lack of certainty regarding the sale of carbon credits under the Swiss compliance scheme significantly diminishes the appeal of CCUS project development. Such projects entail substantial upfront investment costs and correspondingly extended amortisation periods, making them especially unattractive under these circumstances.

Determination of reference scenario

The reference scenario is the most likely alternative to the project scenario, generally being the most economically attractive scenario. A reference scenario is defined once at the beginning of a project and is later compared to the measured project scenario to quantify the emission reductions and ultimately determine the amount of issued carbon credits.

In this blueprint, we can consider potential reference scenarios regarding the capture of biogenic CO₂ on a biogas upgrading plant and the utilisation of CO₂ in concrete. These scenarios are interconnected in the sense that the absence of captured CO₂ would also mean no CO₂ utilisation.

The most likely reference scenario for the capture of biogenic CO₂ is the current business-as-usual case. Biogenic CO₂ is released into the atmosphere due to the absence of regulations and the high investment cost of a capturing unit and the operational costs associated with it. A mandatory capture of these types of emissions also seems unlikely due to the already-mentioned costs and the general concept of biogenic CO₂ being climate-neutral and as part of the natural carbon cycle, it does not contribute to a long-term increase in atmospheric CO₂ levels.

For the utilisation and storage part of the project value chain, the most likely reference scenario is again the business-as-usual case. Due to its novel technology approach, as well as the corresponding investment costs a mandatory utilisation of CO₂ in cement is highly unlikely. The cement industry is already covered by the ETS, and biogenic CO₂ is not in the scope of any legislation.

For both cases, a reference scenario, in which the costs of the project activities reduce drastically and the project scenario becomes economically viable can be ruled out for the time until the compensation obligation discontinues at the end of 2030.

Monitoring plan, monitoring report, and quantification of emission reductions

The monitoring plan, a crucial component of the project description and initial authorization process, outlines all relevant parameters and data to be measured and reported throughout the project's lifecycle. It provides specific requirements for handling data and methods employed to calculate emission reductions. This comprehensive monitoring plan serves as a step-by-step guide, enabling project proponents, third-party validators, and the FOEN to precisely calculate and understand actual emission reductions in the yearly monitoring report. In cases where a parameter

Blueprint 3 – Abroad CCUS value chain

cannot be measured precisely, the estimate must be as accurate as possible, which requires the consultation of supporting scientific measures. Moreover, all emission reductions or parameter estimations must be made conservatively, following the principle of conservativeness, to prevent any overestimation. The yearly monitoring report, verified by the VV and the FOEN, calculates emission reductions for a given year by deducting project emissions and associated project leakage¹⁰ from the reference scenario.

¹⁰ Leakage refers to the change in emissions beyond the project activities that are not directly attributed to but influenced by the project. It can have either a negative impact, resulting in increased emissions, or a positive impact, leading to more emission reductions. Unless negligible, leakage emissions must be considered in the final emission reduction calculation. An example of leakage would be the necessity to offset the reduced energy output and increased use of fossil fuels due to the diversion of biomass from a waste incineration plant to a biogas plant.

6. EU Carbon Removal Certification Framework

Introduced as a component of the European Green Deal on 30 November 2022, the Carbon Removal Certification Framework (CRCF) represents an initiative of the EU Commission to enhance the tracking of carbon removal results in the EU. As the framework will only become operational in the coming years the applicability to our case is uncertain. The case outlined here will likely be eligible as the ongoing deliberations on the utilisation of CO₂ focus on the durability of storage (which can easily be demonstrated in this case). This means that biogas upgrading with CCUS through mineralization in concrete might be among the first project types made eligible for crediting under the CRCF. Should this be the case, this could become a potentially attractive alternative to crediting solely for voluntary carbon markets or even for the Swiss compensation scheme as credits produced in line with the CRCF might qualify for compliance use under EU regulations (perhaps including the ETS) fetching higher prices than elsewhere.

7. Potential (future) crediting and monetisation options

Besides crediting under the voluntary carbon markets, potential revenue under a revised EU ETS, transfer of ITMOs to Switzerland, or crediting under the CRCF, biogas-upgrading with CCUS may in the future also generate credits under the so-called Article 6.4 Mechanism (A6.4M) or credits (from both VCS and A6.4M) may be sold for compliance under CORSIA. Both avenues are outlined in the following.

7.1 Article 6.4 – centralised Mechanism

Though introduced via the same Article 6 of the Paris Agreement, Article 6.4 represents a standalone baseline and credit mechanism (A6.4M). It serves as a UN crediting mechanism fully under UN rules. It will follow a very similar carbon project cycle to that described previously, and methodologies under this mechanism may very much resemble those of established VCM standards. Credits (A6.4ERs) will be issued under the supervision of a UN supervisory body and will be internationally tradeable for countries to use towards NDC delivery (or voluntary offsetting or contribution claims). The A6.4M is expected to become the go-to source of credits for governments that need to purchase credits for achieving their NDC, which over time could become the largest source of demand for carbon credits. Given that the A6.4M has a unique position as a formal UN mechanism with UN-approved methodologies and requirements, it is expected to set the tone also for other crediting standards, which over time may adapt to become similar in their requirements.

7.2 ICAO – an emerging source of demand for credits

CORSIA was launched by the International Civil Aviation Organization (ICAO) in 2016. The main goal is to limit international aviation emissions to 2019 levels, and all participating airlines shall compensate for their emission increases with the purchase and surrender of eligible carbon credits. It is expected to be implemented in three phases: pilot phase 2021–23 (voluntary), first phase 2024–26 (voluntary) and second phase 2027–35 (mandatory).

Eligible standards include the VCS, American Carbon Registry (ACR), Clean Development Mechanism (CDM), Climate Action Reserve (CAR), Gold Standard (GS), China GHG Voluntary Emission Reduction Program, Architecture for Reducing Emissions from Deforestation and Forest Degradation and the Role of Conservation, Sustainable Management of Forests and Enhancement of Forest Carbon Stocks in Developing Countries (REDD+) Transactions, and Global Carbon Council (GCC). Not all credits are allowed from these programs as several limitations have been defined. Limitations are set on the vintages of the activities (i.e. the crediting period must commence after 1 January 2016) or technology type. CORSIA is not expected to generate significant demand for eligible carbon credits during the pilot phase (IETA, 2022) due to the reduction in flights during COVID-19, but it may see greater demand in the first and second phases.

8. Barriers and opportunities for action

An activity of this kind taking place within national borders of a single country would be relatively straightforward from an accounting viewpoint. An important question to clarify, however, is whether (or rather in which parts) the activity is considered to generate results for the cement sector – those would need to account for ETS incentives for VCS crediting (and would not be eligible for Swiss compensation scheme crediting).

As a novel type of carbon project involving numerous different and heterogenous sector actors (biogas upgrading e.g. in the liquid waste sector, transport, and the cement sector for utilisation and storage), it does, however, require developing the requisite basis for mutually beneficial cooperation along the value chain.

In particular, this means developing appropriate institutional arrangements that give clarity regarding ownership and revenue sharing. Developing a CCUS carbon project involves exploring and deciding on the most suitable institutional arrangement and drawing up the matching contractual arrangements so that there is an effective project developer (either one of the value-chain partners, an aggregate entity comprising of several partners, or a service-providing third party) such that the requirements regarding reversal risk (as set out in the methodology and the reversal risk tool) are fulfilled. As the corresponding methodology for utilisation in durable products is under development the specific requirements in this regard remain yet to be seen.

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Making the Swiss Emission Trading Scheme Work for CCS: A Legal Analysis

Ilaria Espa

1. Introduction

Meeting Switzerland's net-zero targets will require the upscaling of investment in carbon capture and storage (CCS) technologies. Based on Switzerland's long-term climate strategy, in particular, an estimated 7 million tons of CO₂ per year coming from large point-source emission sources will need to be captured and stored using CCS technology by 2050 (Federal Council, 2021). In Switzerland, large emitters are, with the exception of waste-to-energy plants,¹ subject to the emission trading system (ETS).

The Swiss ETS is a carbon pricing mechanism that works through the cap-and-trade logic in alignment with the polluter pays principle (Dupuy and Viñuales, 2018). Since 2020, it is linked with the ETS scheme of the European Union (EU), which means that the two systems have to be compatible so that allowances can be mutually recognized (FOEN, 2020). While the price of the ETS allowances has been quite volatile in the past, it has increased significantly in the latest years owing to the (anticipated) reforms of the system (Riechmann, Perner and Peichert, 2022), reaching a record high of EUR 100.34 per metric ton of CO₂ in February 2023 (Statista, 2023).

At the time of writing, CCS is not integrated in the Swiss ETS – meaning that the current *CO₂ Act* does not allow for the accounting of emission reductions from CCS. Swiss industrial installations covered under the scheme are thus still required to surrender emission allowances for the captured and durably stored CO₂. This is not only at odds with what is envisaged under the EU ETS, which already absolves ETS installations of such an obligation and also recently expanded the reach of this exemption regime within the context of the Fit for 55 revision (Directive (EU) 2023/959, recital 69 and Annex I); it also risks further deterring CCS deployment at the pace and scale that is needed in Switzerland.

Accordingly, the newly revised *CO₂ Act* for the period from 2025 to 2030 does envisage full alignment with the EU ETS exemption regime so that Swiss ETS installations will no longer need to surrender emission allowances for the amounts of CO₂ from fossil origin and from process emissions

¹ Waste treatment installations are exempt from the Swiss ETS following the agreements concluded in 2022 between DETEC and VBSA. According to such agreement, the operators of waste treatment installations are obliged to put at least one capture plant into operation by 2030 with minimum nominal capacity of 100,000 tons per year (FOEN, 2022).

that are captured and transferred offsite for the purpose of geological storage or stored in long-lived products such as building materials, provided a number of conditions are fulfilled (Federal Council, 2022). The rationale behind the integration of CCS into the Swiss ETS is to support investment in CCS technologies by means of liberating the resources that would otherwise be needed to buy emission allowances. In other words, the idea is to use the carbon pricing logic inspiring the ETS instrumentally to incentivize CCS technologies.

Allowing ETS operators to avoid the cost of paying the carbon price is an important first step forward in generating the necessary stream of financing for CCS. It cannot, however, suffice in and of itself to ensure the volumes of investment needed for two main reasons. First, it provides with an incentive that corresponds to the value of an ETS allowance – whose price is neither high nor stable enough to provide for the long-term certainty for investors. Second, it places the incentive only at the point of emissions (i.e. the point of capture), and thereby fails to monetize the other components in the chain of CCS operations (i.e. transport and storage) (Marcu, Zaman and Zakkour, 2021) – which amount to comparatively higher costs in the case of Switzerland as a country that lacks geological storage capacity.

Accordingly, this paper seeks to identify options for enhancing the contribution of the Swiss ETS in making CCS deployment financially viable and to suggest potential complementary policy tools for the purposes of ensuring greater predictability and stability of CCS incentives. The paper explores pros and cons of each option in light of its legal implications, focusing on the constraints that arise out of the international obligations assumed by Switzerland both on the bilateral level (i.e. through the EU-CH ETS Linking Agreement) and on the multilateral level (e.g. based on the Paris Agreement and on World Trade Organization (WTO) rules).

2. ETS-based Options

2.1 Crediting Emission Reductions from CCS in the ETS: The Exemption Regime

As already mentioned, the one option that is concretely envisaged in the newly revised *CO₂ Act* starting from 2025 is exempting Swiss ETS installations from the obligation to surrender emission allowances for the portion of CO₂ coming from fossil origin and from process emissions that is durably stored in EEA countries in accordance with the EU CCS Directive or in long-lived products (Federal Council, 2022). The features of the integration of CCS in the Swiss ETS essentially replicate the exemption regime that is already envisaged for the EU ETS after the passing of the new Directive (EU) 2023/959 in May 2023. In this respect, alignment with the EU exemption regime does not pose

problems with the EU-CH ETS Linking Agreement but rather ensures that the two systems do remain compatible when it comes to the accounting of emissions reductions from CCS.

The integration of CCS into the Swiss ETS, however, may raise problems under international trade law depending on how its specific design intersects with those ETS features that have already proven problematic when scrutinized under WTO law, such as the free allocation of emission allowances. At the time being, and similarly to what happens within the EU ETS, the Swiss ETS still accommodates for the granting of free allowances to sectors that are exposed to carbon leakage based on trade and emissions intensity criteria. The number of free allowances is determined in accordance with benchmarks that are determined by considering the best performing 10% of installations in the EU and in the European Economic Area (Bucher, 2023). This regime has not yet been challenged before the WTO dispute settlement system, but scholars converge in considering it extremely likely that it might constitute a prohibited or actionable subsidy within the meaning of the WTO Agreement on Subsidies and Countervailing Measures (SCM) as a “financial contribution” taking the form of “revenue foregone” (as an exception to the default method of auctioning) under Article 1.1(a)(1)(ii) SCM and conferring a “benefit” upon recipient installations as per Article 1.1(b) SCM (Ismer et al, 2023; Espa, Francois and van Asselt, 2022; Bacchus, 2021). Attesting to the soundness of such legal analyses, the United States Department of Commerce recently determined that the EU free allocation regime constituted a countervailable subsidy (US Department of Commerce, 2020; Marcu, Zaman and Zakkour, 2021).

This means that, to the extent that Swiss ETS installations engaging in CCS activities are still granted free allowances, the integration of CCS may likely face a high level of legal risk under the SCM Agreement. This is because the combination of CCS integration with free allocation could lead to over-compensation for Swiss ETS installations engaged in CCS activities, especially if acknowledging CCS-induced emission reductions brings “actual” emissions close to, and eventually below, the benchmark for free allocation. In this case, granting of free allowances would de facto turn them into “surplus” allowances (that is, allowances that would have to be sold or used to cover for emissions coming from other installations owned by the recipient). This would practically translate into a cash transfer scenario, making the regime likely to constitute a “direct transfer of funds” within the meaning of Article 1.1(a)(1)(i) SCM and conferring a “benefit” upon installations engaged in CCS activities.

Here again, the existence of a subsidy would likely trigger actionability and countervailability due to the ascertaining of adverse effects caused to the interests of other WTO members, either in the form

of injury to their domestic industry/ies (e.g. in those cases where the establishment of carbon-neutral industrial sectors in other countries could be shown to suffer from “material retardation” due to fiercer competition of subsidized Swiss imports coming from installations subject to the (free allocation under the) ETS, as per Article 5 SCM) or in the form of serious prejudice under Article 6.3 SCM (e.g. in those cases where the effects of the Swiss ETS regime would endanger displacement of the imports of like products in the Swiss markets or in export markets (Ismer et al, 2023)).

Accordingly, it is advised that the integration of CCS into the Swiss ETS develops separately from the regime of free allocation so that ETS installations remain exposed to the full costs of their non-captured carbon emissions. While this means that the potential for using the ETS mechanics to generate an incentive that is higher than just the price of emission allowances (i.e. the value of the absolved emission allowances corresponding to the amounts of CCS-induced emissions reductions plus the “surplus” allowances linked to free allocation) will remain untapped, isolating the exemption regime from what is already considered the most controversial feature of the Swiss/EU ETS under international trade law would shield it from potential legal challenges (which would be costly and lengthy) and/or from countervailing actions that could reduce market access opportunities for Swiss firms. It would furthermore signal the willingness to use the ETS as an instrument for incentivizing CCS deployment through the reverse mechanism, that is, through sending a stronger carbon price signal.

Importantly, the newly revised *CO₂ Act* will include the normative basis for establishing a trajectory for the phasing out of free allocation that is in line with the EU ETS trajectory. Such an alignment is not only expected to contribute strengthening the price of emissions allowances, but it is also required to ensure the equivalence sought under the EU-CH ETS Linking Agreement (Bucher, 2023).

2.2 Strengthening the ETS to Produce a Stronger Carbon Price Signal

To the extent that free allocation is not a legally sound option to create additional value for Swiss ETS installations to engage in CCS activities, the exemption regime envisaged for CCS-induced emission reductions in the newly revised *CO₂ Act* would fall short of ensuring the financial viability of CCS deployment owing to the differential between the carbon costs avoided by ETS installations (i.e. the value of the to-be-absolved emission allowances) and CCS costs. This does not mean, however, that the ETS could not be suitable to create a strong enough incentive for investment in CCS technologies on the part of Swiss installations *ab absoluto*. On the one hand, the exemption regime could liberate increasingly larger revenue streams as long as the ETS becomes capable to generate a progressively higher (and more stable) carbon price signal. On the other hand, the added

costs of climate-neutral production are set to decrease due to learning effects (Ismer et al, 2023). The combination of these two trends could eventually lead to full equalization of the added costs entailed in engaging in CCS for Swiss ETS installations through the exemption regime.

As to the first aspect, both the EU and the Swiss ETS have progressively been reformed with a view to overcome a number of structural problems leading to the price volatility and oversupply of emission allowances (Riechmann, Perner and Peichert, 2022). The main critical design features to this end include the tightening of the cap through the increase of the so-called linear reduction factor, the phasing out of free allocation, and the introduction of a market stability mechanism that reduces auction volumes if the quantity of emissions allowances in circulation exceeds a certain threshold (ICAP, 2023). The Swiss ETS essentially aligns to the EU ETS regime when it comes to the trajectory to be followed for the sake of maintaining the equivalence needed under the EU-CH ETS Linking Agreement. Importantly, the Fit for 55 reform of the EU ETS directly concerns all such main elements (e.g. the linear reduction factor goes from 2.2% to 5.10% from 2024 to 5.38% from 2027; free allocation is going to be phased out by 2034; the market stability reserve is streamlined, with the extraction rate set at 24% and rationalized triggering scenarios;); the goal is to sustain a rapid but gradual increase in the price of emission allowances, which is meant to bring emissions in covered sectors down from 43% to 62% by 2030 compared to 2005 levels (Directive (EU) 2023/959, recital 39). The newly revised *CO₂ Act* is accordingly set to transpose the EU ETS innovations into the Swiss scheme, with the objective to reach a further reduction in covered emissions ranging from 15% to 20% by 2030 (Bucher, 2023).

While it is expected that such improvements will continue strengthening the carbon price signal, it is extremely difficult to predict what will be the pace and magnitude of the medium- to long-term increase in the price of allowances and therefore to ascertain whether these changes could ensure the predictability and stability of the incentive for CCS (Marcu and Fernandez, 2022). These considerations furthermore intersect with the uncertainty surrounding the time lag required to sufficiently abate the learning costs to engage in CCS technologies so that full equalization is eventually achieved based on the evolution of the price of emission allowances. This second aspect is in fact dependent on the specifics of CCS deployment (scale, pace, etc.), which may in turn be hampered or delayed by the insufficient, or insufficiently stable incentive in the short-term (Ismer et al, 2023). What is certain, however, is that any residual differential that is likely to remain after the implementation of the latest revision of the ETS might be fixed through design reform only for the period after 2030 due to the time dynamics surrounding the legislative process anticipated for the next revision of the *CO₂ Act*. In this respect, the carbon pricing exemption logic espoused to integrate

CCS into the Swiss ETS would not suffice alone to meet the challenge of scaling up investment in CCS deployment during this present critical decade. Complementary options to carbon pricing should therefore be considered for the purposes of ensuring the financial viability of CCS technologies (Zakkour and Heidug, 2019; Martin-Roberts et al, 2021; Marcu, Zaman and Zakkour, 2021).

3. Complementary Options

This section will explore pros and cons of different policy tools that could work complementarily to the Swiss ETS for the purpose of strengthening support for CCS deployment. The rationale is to assess the legal challenges and opportunities that may be posed by a combination of instruments that could work synergistically with the exemption regime envisaged under the Swiss ETS and thus contribute encouraging the uptake of CCS technologies within Swiss ETS installations.

3.1 A Carbon Border Adjustment Mechanism Substituting Free Allocation

As mentioned above, the innovations introduced in the ETS design, on the one hand, and the phasing out of free allocation, on the other hand, are expected to strengthen the carbon price signal and accordingly increase the environmental effectiveness of the ETS. While a rise in the price of emissions allowances is to encourage emissions reductions (including through CCS) among covered installations, carbon leakage risks may materialize as a result of the increase in the ETS costs against the backdrop of very asymmetric carbon constraints imposed on competing firms situated in other jurisdictions, absent any safeguard to “level the playing field” (Espa, 2022).

Given the planned phasing out of free allocation, the EU recently decided to introduce the so-called Carbon Border Adjustment Mechanism (CBAM) with a view to address the problem of carbon leakage in an alternative, arguably more environmentally sound and financially sustainable, way (Espa and Holzer, 2023). The EU CBAM is a trade instrument that works by levelling *up* the carbon price arising out of the ETS for foreign producers, rather than levelling it down – and thus muting it – for ETS installations (Pirlot, 2022). This way the EU could at the same time continue tightening of the emissions cap in the EU ETS under a gradual phase out of free allocation and address competitiveness by means of extending the ETS carbon price to imported products. Following a similar logic, the CBAM could also include adjustments on the export side so that the ETS carbon price is rebated on domestic products destined for exportation for equalization purposes in foreign markets (Espa, 2022). For the time being, however, the EU excluded export rebates in the design of the CBAM. It however contemplated that they might be introduced after the end of the transitional

period, provided that an assessment of the effects of the ETS and the CBAM on EU exports shows evidence of export-related carbon leakage risks (CBAM Regulation, art 30.5).

The general concept behind the EU CBAM is not new in that countries have long resorted to “level the playing field” measures in the fiscal domain through the use of so-called border tax adjustments (BTAs) (Dordi, 2017). Expanding the concept of BTAs to measures that are different than explicit taxes, however, entails a number of complications. Although the EU CBAM Regulation states that “the CBAM complements the [EU ETS] by applying an equivalent set of rules” (EU CBAM Regulation, art 1(2)), the equalization logic requires that the amount of the charge to be imposed (or rebated) at the border reflect the variability in the price of carbon that results out of a market-based mechanism such as the ETS. This also means that the amount of the charge would need to be corrected to reflect the existence of any carbon costs already paid (or, in the case of installations engaging in CCS, netted out) in the country of origin of imported products (import-side BCA) or in the country of destination of domestic products (export-side BCA), which may in turn also resort to other than explicit carbon taxes such as ETS schemes or even to implicit carbon pricing instruments such as carbon standards (Espa, 2022). Both aspects are further complicated by the fact that, contrary to product-related inputs, carbon is not actually incorporated into the products but just released during their processes and production methods (PPMs); the level of the charge imposed (or rebated) through the BCA might therefore change depending on how the carbon content “embedded” into goods is calculated (Espa, Francois and van Asselt, 2022).

For all these reasons, the EU CBAM is not only likely to prove very complex and burdensome to implement, but it remains extremely contentious as a climate-motivated trade instrument. The Swiss Federal Council has accordingly considered it premature to decide on the introduction of a border carbon adjustment *à la* EU CBAM (Federal Council, 2023). The matter could however be reconsidered after 2026 when the EU Commission will have presented its intermediate assessment.

While there is no immediate urgency to align to the EU decision and introduce a CBAM in concert with the Swiss ETS as a matter of the EU-CH ETS Linking Agreement (Lanz, 2023), such an instrument could arguably be designed in a way as to further contribute incentivizing CCS among ETS installations to the extent that it would afford protection to those large emitters (e.g. cement producers) that are already the main targets of the ETS exemption regime for CCS (see section 2.1). The level of protection would depend on, inter alia, the degree of and the modalities for recognition of CCS in the methodologies used for calculating embedded emissions (Marcu et al, 2023) and on whether and how such methodologies would (also) be combined with adjustments on the export side

that could help Swiss producers gain further competitiveness in foreign markets by means of getting rebates linked to the crediting of CCS technologies.

Incorporating such design features, however, would make the CBAM even more experimental and prone to challenges under WTO law. While it remains very difficult to predict the outcome of a potential future WTO dispute, at issue is in particular whether such a measure could be held compatible with the WTO rules on non-discrimination (national treatment principle and most-favoured nation clause) and under the SCM Agreement; and, if not, whether it could still be justified under the general exceptions available for measures taken for certain environment-related policy objectives. These rules are briefly discussed here with regard to the main compatibility issues envisaged for the EU CBAM, but the same arguments could apply *mutatis mutandis* in case of a Swiss CBAM, and even more so should such a measure incorporate design features specifically targeting CCS.

As to the WTO rules on internal non-discrimination, the main problem lies in the fact that the EU CBAM is a PPM measure based on the carbon footprint of products but, under the national treatment principle, which requires that WTO members do not treat foreign product disfavouredly vis-à-vis domestic like products, it seems most likely that products with different carbon intensities would be considered ‘like’ products (GATT Agreement, art III). Differentiating between carbon-intensive products and low-carbon products might therefore not be acceptable if the former are the imported ones (due to lower carbon constraints in the countries of origin) and the latter are the domestic ones (due to the stronger ETS carbon price that is adjusted). This is even more so if one considers that, depending on the specific features of the measure to be adjusted, it might very difficult (when not impossible) to impose on imported products a carbon price that is equivalent to the price that such products would have borne domestically due to the challenges entailed in tracking and certifying what is the exact carbon content of foreign products. In the case of the EU CBAM, for instance, the choice to combine the method of actual embedded emissions with default values purports to ensure a trade-off between accuracy and practical feasibility (Espa and Holzer, 2023); in practice, however, it may entail that imported products are discriminated against if default values are punitive, and especially so if compliance costs prove prohibitive for covered firms (Espa, Francois and van Asselt, 2022). Further problems in this respect may arise depending on the choice of methodologies to treat CCS in the calculation of actual emissions of imported products – and especially in case there is a lack of recognition of CCS as it seems to be the case for the time being in discussions concerning the CBAM Regulation implementing acts (Marcu et al, 2023).

As to the WTO rules on external non-discrimination, the CBAM also risks running counter to the most-favoured nation (MFN) principle (GATT Agreement, art I:1) to the extent that it includes “exclusion” features aimed at excluding either in part or in full third countries from the measure’s scope of application depending on their level of climate ambition (Espa and Holzer, 2023). In the case of the EU CBAM, for instance, imported products coming from Switzerland are excluded given that its ETS is linked with the EU ETS, whereas a CBAM “discount” applies for the purpose of crediting other explicit carbon pricing policies that third countries might have in place (CBAM Regulation, Article 9). Similar features would need to be replicated in the case of a Swiss CBAM, especially for what concerns the full exemption granted to the EU as a matter of the equivalence ensured through the EU-CH ETS Linking Agreement.

The example of the EU CBAM shows that even the most carefully designed border carbon adjustment faces high risks of being found incompatible with GATT rules on non-discrimination. In this case, the only option to pass WTO scrutiny would be to invoke the “environmental” exceptions contained in Article XX GATT – namely, the public health exception under Article XX (b) and the conservation of exhaustible natural resources exception under Article XX (g). With regard to the former, the measure would need to prove “necessary” to protect human, animal and plant life or health from climate change effects. With regard to the latter, the measure would need to be “related to” the conservation of a safe and stable climate system (an exhaustible natural resource in and of itself) and applied evenhandedly (that is, in connection with a similarly restrictive domestic measure such as a carbon tax or an ETS imposing an equivalent price). Although the necessity test is slightly different (and more stringent), than the relatedness requirement, it could be argued that based on existing WTO case law there could likely be room for the CBAM to be provisionally justified under either of the exceptions (Holzer, Cottier and Espa, 2022). The inclusion of CCS-specific features would likely not change this conclusion, especially to the extent that the crediting of emission reduction from CCS would be decoupled from free allocation (see section 2.1).

What seems less convincing is that the CBAM might meet the requirements of the so-called chapeau to Article XX GATT, which requires that a provisionally justified measure be not applied “in a manner which constitutes an arbitrary or unjustifiable discrimination between countries where the same conditions prevail, or a disguised restriction on international trade.” This boils down to ensuring that the CBAM is flexible enough to exclude imports from countries having a carbon leakage safeguard in place (Espa and Holzer, 2023). The problem here lies in the difficulty to determine the equivalence between explicit carbon pricing and implicit carbon pricing, which might lead to the

choice of either neglecting non-pricing climate policy measures or defining complex methodologies to calculate implicit prices that might practically work by disfavours certain non-pricing instruments. This is especially true in the case of methodologies that would also take into account whatever domestic discount imported products might already enjoy as a matter of national crediting for CCS, which is arguably not necessarily feasible or straightforward in the case of implicit carbon pricing, depending on the specifics of the policy. Such an outcome could lead to allegations of arbitrary or unjustifiable discrimination among countries where the same conditions (in terms of effective carbon prices) prevail. Against this backdrop, the choice of crediting for explicit carbon prices only is arguably the Achilles' heel of the EU CBAM, as it currently stands, for the purposes of the chapeau of Article XX GATT (Espa and Holzer, 2023). Significantly, furthermore, such a feature runs the risk of creating tensions with the principle of common but differentiated responsibilities and respective capabilities (CBDR-RC) informing the Paris Agreement (Holzer, Cottier and Espa, 2022). This principle arguably requires to either partially or fully exempt least-developed countries and small islands developing states' imports and/or to use CBAM revenues (at least partly) to contribute towards funding the decarbonization of their industries and thus help them minimize the negative impact raised by the measure (Marin Duran, 2022). Neither feature is included in the EU CBAM design at present, however.

Similar if not stronger impediments will likely be faced in case of a CBAM including adjustments on the export side due to SCM compatibility challenges. The issue boils down as to whether export rebates could qualify as a subsidy within the meaning of Article 1 of the SCM Agreement in the first place. This would depend on the specific design features of the export adjustment mechanism, which could range from exemptions in the form of free allocation of allowances to monetary rebates or non-monetary rebates granted through so-called adjustment allowances or certificates (Marcu et al, 2022). Free allocation, in particular, seemed the option preferred by the European Parliament, at least in the short-term, based on its position adopted on 22 June 2022 (European Parliament, 2022). The final EU CBAM Regulation, however, does neither envisage to go forward with export rebates, nor does it explicitly mention free allocation (or any other form of compensation upon exportation) as a variant to be considered to address potential export-related carbon leakage risks. As mentioned earlier, it only contemplates the possibility to introduce adjustments on the export side only after the end of the transitional period and upon further assessment by the Commission (EU CBAM Regulation, art 30.5).

Caution over the inclusion of export rebates more generally, and free allocation as a form of export adjustment more specifically, reflects the high level of legal uncertainty surrounding these features

under the SCM Agreement. Many have in fact noticed that, based on existing WTO case law, it cannot be excluded that export rebates constitute a financial contribution under Article 1.1.(a)(1) in the form of a direct transfer of fund, revenue foregone or provision of a good or service, with revenue foregone being the most likely fit for free allocation (Holzer, Cottier and Espa, 2022). In the context of a recent US Department investigation into countervailing duties on the import of forged steel fluid end blocks from Germany and Italy, the European Commission did try to defend free allocation as an “inherent component” of the ETS, that is, a system that must be considered in its entirety. It also argued that for this reason it could neither constitute a financial contribution nor confer a benefit within the meaning of the SCM Agreement, as it would simply reduce the net regulatory burden arising out of the ETS for domestic producers. As already mentioned, however, this argument did not fly and the US Department of Commerce considered free allocation a countervailable subsidy (US Department of Commerce, 2020).

Ultimately, it remains uncertain how export rebates would qualify under the SCM depending on their exact form. Were they considered a subsidy within the meaning of Article 1 ASCM, however, they would most likely qualify as a prohibited export subsidy under Article 3 ASCM (Holzer et al, 2022).

In light of such uncertainties, the costs entailed in designing and implementing a Swiss CBAM *à la* EU CBAM that could stand a chance to be considered compatible with WTO rules are admittedly high, although it is no mystery that certain Swiss sectors, *in primis* the cement sector, would gain out of the implementation of a Swiss CBAM (Lanz, 2023). For what concerns CCS, furthermore, the margin of manoeuvre to shape a Swiss CBAM in way that could contribute to create additional value for CCS deployment is extremely limited – although one could also envisage that the proceeds coming from the CBAM revenues be earmarked to CCS through, for instance, contributing to financing carbon contracts for difference (see section 3.2) – and seemingly comes at the expenses of exposing the measure to higher legal risks (e.g. in the case free allocation would be granted as a form of export rebate for installations engaged in CCS).

3.2 Carbon Contracts for Difference (CCfDs)

Given the price differential that will likely remain in the short- to medium-term between the carbon costs borne by ETS installations based on the price of emission allowances and CCS costs, de-risking instruments such as carbon contracts for difference (CCfDs) could provide for an additional support measure through which the government could contribute to the added costs of CCS incurred by Swiss ETS installations.

CCfDs are carbon-connotated versions of contracts for difference (CfDs), which are usually long-term contracts between governments, on the one hand, and economic operators, on the other hand, whereby payments can flow from the former to the latter and vice versa depending on the difference between the reference price and a pre-agreed level (the so-called strike price), which reflects the expected costs (e.g. investment costs, operating costs and/or capital expenditures) for the operators (Marcu and Fernandez, 2023). The idea is to help hedging against volatile prices in order to stabilize the revenues at a pre-determined level for the duration of the contract. Typically, CfDs have been used to provide incentives for decarbonizing the electricity sector (Ismer et al, 2023). *Mutatis mutandis*, CCfDs can be specifically used to address the carbon revenue stream as a means to either support the uptake of a specific technology (e.g. CCS technologies) or to trigger the transformation of entire industries (e.g. the cement sector) more generally.

Reflecting such potential, CCfDs have not only started mushrooming in a number of the EU member states such as the Netherlands, Germany and the UK (Marcu and Fernandez, 2023); they have also been explicitly envisaged as a tool for fostering emission reductions in industrial sectors covered by the ETS through the scaling-up of climate-friendly technologies such as CCS within the context of the latest Fit for 55 reform (Directive (EU) 2023/959, recital 59 and Article 10a(8)). Under the new Directive (EU) 2023/959, CCfDs are defined as “a contract between the Commission and the producer, selected through a competitive bidding mechanism such as an auction, of a low- or zero-carbon product, and under which the producer is provided with support from the Innovation Fund covering the difference between the winning price, also known as the strike price, on the one hand, and a reference price derived from the average price of allowances, on the other hand” (Directive (EU) 2023/959, recital 59). Importantly, the declared goal is to support new technologies by ensuring to ETS installations “a price that rewards CO₂ emission reductions *above* those induced by the prevailing carbon price level in the EU ETS” (ibid., emphasis added). The instruments chosen to ensure affordability of CCfDs spending is the Innovation Fund, which is financed with the proceeds coming from the auctioning of EU emission allowances and which has also been significantly strengthened under the EU ETS revision (Directive (EU) 2023/959, Article 10a(8)). The idea is to hedge against fluctuations of the EU ETS allowances’ prices – and therefore increase bankability and financing of projects (Marcu and Fernandez, 2023) – , while at the same time avoiding excessive spending through a competitive discovery process such as competitive bidding (auctions) informing the award mechanism.

While it is too early to assess lights and shades of the mechanism as it is envisaged in the revised EU ETS directive, the decision of the EU to count on CCfDs signals the awareness of the insufficiency

of the exemption regime to trigger the necessary volumes of investment in new technologies needed to meet the Unions' net-zero targets such as CCS. At the same time, it also reflects the relatively high disbursement capacity available under the Innovation Fund after the EU ETS revision (Directive (EU) 2023/959, Article 10a(8)). Such a capacity (expected to raise up to EUR 47 billion by 2030) dwarfs the volumes that might be available in Switzerland were a similar mechanism funded by the proceeds coming from auctioning of Swiss ETS allowances (e.g., in 2022, such revenues amounted to CHF 43.6 million according to ICAP, 2023).

And yet, the analysis above (see section 2.1) shows that additional value for the monetization of investment in CCS technologies is needed when it comes to fostering emission reductions in those large emitting sectors covered under the ETS given the current (and projected) price of allowances. This is even more so considering that the funding mechanisms recently approved after the passing of the June 18, 2023 referendum would not be accessible by ETS installations. In the case of the support measures made available under the new *Climate and Innovation Act* (up to CHF 200 million/year at least until 2030), a specific provision was included that seemingly impedes ETS installations to figure as recipients to the extent that no contribution will be paid for measures that already benefit from other incentives or that are integrated into an instrument for reducing greenhouse gas emissions (Climate and Innovation Act, art 6(4)). In the case of the *Stiftung Klimarappen* (CHF 60 million for 2025-2030), ETS-projects are excluded since reduction of emissions covered by ETS is not eligible under Switzerland's compensation scheme (see section 3.3).

For now, the use of CCfDs has not been envisaged in Switzerland nor being discussed in the context of the legislative process leading to the adoption of the newly revised *CO₂ Act* for 2025-2030, seemingly given that the ETS exemption regime for CSS is going to be the main incentive measure espoused by Switzerland. For the period after 2030, however, the potential to use CCfDs as targeted instruments for supporting the upscaling of CCS technologies could be explored with a view to fully equalize the costs of carbon capture incurred by Swiss ETS installations. Under such scenario, the reference price would consist of the average ETS allowances' price whereas the strike price would be defined through competitive bidding with a view to determine a pre-agreed level prices based upon the mentioned reference price, the expected costs of capture, avoided carbon costs and expected return for CCS investment (Marcu and Fernandez, 2023).

One of the issues most often raised with regard to CCfDs is the budgetary uncertainty that this instrument creates for both companies and public institutions due to the difficulties entailed in predicting the exact evolution in the price of emissions allowances (Marcu and Fernandez, 2023).

Most typically, in the short- to mid-term it would be that governments bear the costs of supporting the uptake of new (CCS) technologies, but only until “a rise in global carbon price improves returns of carbon-neutral installations [so that] the payouts by governments to producers would be lower or even negative” (Ismer et al, 2023). A calibrated use of CCfDs could furthermore prevent excessive spending to the extent that (i) the level of support (strike price) would be set by the market through a competitive discovery process such as auctioning; and (ii) the reference price would keep on growing as a result of the incremental strengthening of the Swiss ETS inducing a stronger carbon price signal. This is not to say that support for CCS through CCfDs would prove unproblematic from a political standpoint, and this is especially considering the relatively scarce resources that could be available as a matter of ETS design through the proceeds of the revenues. When assessing the opportunity to conceive of additional budgetary outlays for funding CCfDs in the short- to mid-term (e.g. in the case Switzerland implements it, one such source could also be CBAM revenues), however, one should bear in mind that carefully designed CCfDs not only have the potential to minimize overall funding needs but also carry the opportunity for governments to recuperate assumed costs as the price of ETS allowances rises (Richstein, 2017; Ismer et al, 2023).

Irrespective of potential difficulties to decide on the allocation of the necessary resources at the political level, from a legal standpoint it is worth noting that the implementation of CCfDs is arguably not very likely to raise hurdles when it comes to its compatibility with WTO rules. This is mainly because, based on existing WTO jurisprudence, a scheme that is based on a competitive discovery process such as auctioning would not be considered to be granting a “benefit” within a meaning of Article 1.1(b) SCM, and therefore it would not qualify as a subsidy captured under the Agreement (Ismer et al, 2023). By all means, such conclusion might change depending on how any free allocation would be accounted in the definition of the reference price, for the reasons explained above (see section 2.1). To the extent that this option might be considered for the period after 2030, and in light of the prospected trajectory for the phasing out of free allowances in the Swiss ETS, such worst-case scenario is however not very likely to materialize.

3.3 A Carbon Storage Obligation to Support Sink Enhancements

With a view to strengthening support for the entire CCS chain rather than just focus on the value of emission reductions at the point of capture, it has been proposed to supplement carbon pricing policies such as the Swiss ETS with a carbon storage obligation or CSO (that is, “the obligation to geo-sequester a percentage of carbon embedded in a product, ... arriving eventually at 100% for the target date of net carbon neutrality”) to be met exclusively through carbon storage units (CSUs) granted to

storage entities per each ton of CO₂ that is geo-sequestered (Marcu, Zaman and Zakkour, 2021). According to the proponents, the existence of a CSO obligation will create a demand for CSUs, which can trigger new streams of financing for the creation of carbon storage availability and supply consistent with the goal to reach net-zero targets. In other words, a CSO obligation met through CSUs would render geo-sequestration through storage financially viable (Marcu, Zaman and Zakkour, 2021).

Such a framework could be realized by Switzerland unilaterally or within the context of the multilateral nationally determined contributions (NDCs) regime developed under the Paris Agreement (Paris Agreement, art 4). This would imply that Switzerland establishes a(n ideally ratcheting) CO₂ storage target to be reached at future points in time either as a matter of domestic legislation/policy and/or within Switzerland's own NDC (Marcu, Zaman and Zakkour, 2021). Importantly, the target would not need to be reached exclusively domestically and – most importantly for Switzerland, as a country lacking geological storage capacity for the time being – through trans-national CCS activities (Marcu, Zaman and Zakkour, 2021). CCS clubs could also develop among those countries that would include CCS targets in their NDCs for the purposes of piloting the CSU approach (Zakkour and Heidug, 2019; Marcu, Zaman and Zakkour, 2021). Under the proposal, what would happen in practice is that private entities such as fossil fuels manufacturers or importers “would be subject to a ratcheting obligation to offset the embodied carbon, with CSUs providing the means of compliance. The CSOs would be surrendered to government, which in turn could also use it towards fulfilment of a geological CO₂ storage target in its NDCs” (Marcu, Zaman and Zakkour, 2021, also citing Hepburn et al, 2020 and Kuijper et al, 2021).

It should however be noticed that Switzerland already has its own national compensation scheme, whereby manufacturers and importers of fossil motor fuels are requested to offset part of the CO₂ emissions resulting from their release. To do this, they can submit attestations coming from, inter alia, carbon storage projects (FOEN, 2022). The interplay between the Swiss compensation scheme (i.e. a domestic compliance market) and the potentially international market for CSUs would therefore need to be worked out properly with a view to sustain the price of such units and therefore the supply of carbon storage capacity. Developing a CSUs market under the umbrella of Article 6 of the Paris Agreement might likely constitute a promising option to ensure the quality and integrity of CSUs (Marcu, Zaman and Zakkour, 2021); in the case of Switzerland, furthermore, it might also provide with an interesting option to secure a sufficiently large pool of carbon storage projects to be realized in partner countries to reach its net-zero targets. While the specifics of Article 6 activities are yet to be fully operationalized, it is worth noting that, to the extent that the mechanism would be

implemented in alignment with the Paris Agreement rulebook, it stands a comparatively higher chance to pass the WTO law test due to the mutual supportiveness approach espoused by WTO dispute settlement bodies when assessing the compatibility of trade-related measures (*in casu*, CSU transactions) employed in accordance with multilateral environmental agreements (Holzer, Cottier and Espa, 2022).

Finally, to the extent that CSUs would develop as Article 6-aligned credits, prospects for granting them admissibility within the Swiss ETS for the purposes of compliance could be explored. Crediting CSUs under the Swiss ETS could provide with an additional incentive to those covered installations that already engage with CCS activities without yet getting to the full equalization of incurred costs through the ETS exemption regime (see section 2.1). At the same time, however, it would be extremely important to ensure that accepting CSUs to count towards Swiss ETS compliance would not drive down the price of emission allowances – which, in turn, would eviscerate the exemption regime. A similar trajectory occurred after acceptance of credits from Clean Development Mechanism (CDM) and Joint Implementation (JI) credits during the first phases of the EU ETS, which led the Union to ultimately opt for the non-admissibility of such credits in the fourth phase (2021-2030) (Riechmann, Perner and Peichert, 2022). Accordingly, quantitative and qualitative limits should be defined with a view to make CSUs' admissibility instrumental to compensate for the incentive gap remaining as a matter of the ETS exemption regime for CCS, and only until it exists. Admittedly, a major limitation to this approach would be posed by the prevailing price level for CSUs: granting their admissibility for the sake of ETS compliance could work as an additional incentive for ETS installations only to the extent that the price of CSUs remained sufficiently lower than the price of emission allowances so as to cover for any residual differential. Provided this would be the case, however, such a mechanism could at once create additional value for CCS both at the point of capture and at the point of storage.

Importantly, deciding upon the admissibility of CSUs into the ETS would not be a matter of Swiss ETS design to be defined in isolation, as the details of operationalization could affect the price of emission allowances, and therefore potentially impact on the equivalence to be maintained between the Swiss and the EU emission trading schemes. Accordingly, Switzerland would likely not be in the position to introduce such innovations on its own without running counter to the EU-CH ETS Linking Agreement. It would therefore be necessary that the EU and Switzerland agree on the terms for granting such admissibility with a view to avoid structural oversupply of allowances scenarios. Prospects would arguably not be so slim considering that there is a real chance that the EU might benefit from cooperating with Switzerland within a CCS club for the purposes of scaling up

investment in carbon capture and storage, provided that it has just recently assumed an EU CO₂ injection capacity target within its recent Net-Zero Industry Act (European Commission, 2023).

4. Conclusions

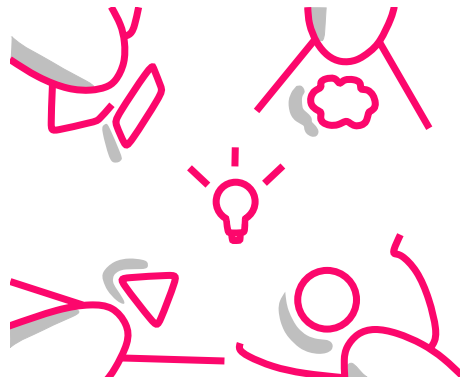
This report aims at exploring potential options suitable to make the Swiss ETS instrumental to trigger investment in CCS technologies. To this end, it provided with an analysis of the Swiss legal landscape governing the ETS in general and of the prospective integration of CCS in particular, always against the backdrop of the EU experience. The analysis identified existing gaps, challenges and opportunities arising out of the current legislation, on the one hand, and the state of and timeframe for the legislative process anticipated for current and future revisions of the *CO₂ Act*, on the other hand. Accordingly, it worked on the definition of a combination of instruments that could altogether contribute encouraging the uptake of CCS technologies among ETS installations in concert with the exemption regime already envisaged to kick-off from 2025. It prioritized those options that could (i) be built-in within the Swiss ETS and operate synergistically with the exemption regime in the short-to medium-term; (ii) increase Switzerland's prospects for collaboration with other CCS like-minded countries; and, (iii) exhibit a higher chance to be found compatible with EU-CH ETS Linking Agreement and with Switzerland's international obligations as arising under WTO law and climate change law.

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Stakeholder Engagement for CCTS/CCUS in Switzerland

Deliverable D5.5 of DemoUpCARMA: Stakeholder Map and Recommendations for Stakeholder Engagement

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Contents

Abbreviations	3
Summary	4
Zusammenfassung auf Deutsch	5
1. Introduction	6
1.1 Objectives and Research Questions	7
1.2 Technical and Political Context	7
1.3 Stakeholder Engagement	9
2. Methods	11
2.1 Stakeholder Mapping Approach	11
2.2 Data Acquisition and Analysis	12
3. Results	13
3.1 Stakeholder Groups (Q1)	13
3.2 Positions by Stakeholders in Switzerland	16
3.2.1 Premises (Q2)	16
3.2.2 Interests and Scopes of Influence (Q3)	19
3.3 International Stakeholders (Q1b)	23
<i>Solution Providers</i>	23
<i>CDR Buyers and Marketplaces</i>	23
<i>Policy Makers and Regulators in Europe</i>	24
<i>Associations and Civil Society in Europe</i>	24
<i>CCTS/CCUS Pioneer Projects</i>	25
4. Recommendations for Stakeholder Engagement (Q4)	26
5. Conclusion	26
6. Acknowledgment	27
7. References	28
8. Annex	30
A1. List of Stakeholders in Switzerland	30
A2. International Stakeholders with Potential Relevance for Swiss CCTS	32
A3. Interviewees by Stakeholder Group	34
A4. Interview Questions	34
A5. Questionnaire	35

Abbreviations

BECCS	Biomass for Energy with Carbon Capture and Storage
CBAM	Carbon Border Adjustment Mechanism
CC	Carbon Capture
CCS	Carbon Capture and Storage
CCTS	Carbon Capture, Transportation and Storage/Sequestration
CCU	Carbon Capture and Utilization
CCUS	Carbon Capture, Utilization and Storage/Sequestration
CH	Switzerland
CO ₂	Carbon Dioxide
CO ₂ -EOR	CO ₂ -Enhanced Oil Recovery
CDR	Carbon Dioxide Removal
DAC	Direct Air Carbon Capture
DACCS	Direct Air Carbon Capture and Storage
DemoUpCARMA	Demonstration and Upscaling of CARbon dioxide MANagement solutions for a net-zero Switzerland
EU	European Union
ETS	Emissions Trading System
FOEN	Federal Office for the Environment
GHG	Greenhouse Gas
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
KIG	Swiss Climate and Innovation Act
NET	Negative Emission Technologies
NGO	Non-Governmental Organization
NPO	Non-Profit Organization
SFOE	Swiss Federal Office of Energy

Summary

To achieve the Swiss climate goals by 2050, carbon capture transportation/utilization and storage (CCTS/CCUS) can play a key role to mitigate “hard-to-abate” emissions. DemoUpCARMA is a pilot project that evaluates the feasibility and potential of two pathways and their upscaling: (i) CO₂ utilization and permanent storage in recycled concrete in Switzerland (CCUS), and (ii) CO₂ transport and permanent storage in geological reservoirs in Iceland (CCTS). The realization of CCUS and (cross-border) CCTS pathways requires both the engagement with existing and the creation of novel infrastructures, value chains, business models, laws and regulations. Furthermore, trade-offs, side-effects and costs can affect a multitude of interests. Therefore, relevant stakeholders include a broad range of organizations and interest groups from private and public sectors, as well as the civil society. With this report we present a stakeholder mapping and position analysis, and develop recommendations for further action in the field of communication and stakeholder engagement around CCTS/CCUS related policy making and implementation projects.

To conduct a stakeholder analysis for CCTS/CCUS in Switzerland, we used a multi-faceted approach. This involved conducting 17 semi-structured interviews, administering a questionnaire, and workshops, as well as informal exchanges with stakeholders. We mapped relevant Swiss and international stakeholders into groups based on their interests and scopes of influence (Research Questions 1 & 3), assessed their premises (Q2), and derived recommendations to guide stakeholder engagement and decision-making for CCTS/CCUS implementation (Q4).

Our results, among others, outline the interests and scopes of influence of thirteen partly overlapping stakeholder groups in Switzerland and give insights into which opportunities, challenges and systemic determining factors and boundary conditions (“systemic tipping points”) they perceive with regards to an upscaling of CCTS/CCUS.

We found that currently active stakeholders are mainly advocates of CCTS/CCUS. A wider, potentially more cautious range of stakeholders will only get involved once “things get real”. They are currently not very familiar with the topic. Individuals are advocating for the topic within their organizations and towards other stakeholders, while at the same time developing solutions and basis for decision-making under uncertainty. Decision-makers who position themselves as observers and cautioners want to see proof that CCTS/CCUS (1) makes sense both for climate mitigation and sustainability & (2) is a low-risk path from a business/economic perspective. Inclusive decision-making is key to best coordinate advocates efforts in overcoming hurdles while at the same time mitigating acceptance risks.

Our findings and recommendations are intended to help institutions and project developers to proactively engage with relevant stakeholders in Switzerland and internationally, considering their dynamic interests and responsibilities related to CCTS/CCUS as well as the diverging levels of knowledge and interest within organisations and stakeholder groups.

Zusammenfassung auf Deutsch

Um die Schweizer Klimaziele bis 2050 zu erreichen, können CO₂-Abscheidung, -Transport, -Verwertung und -Speicherung (CCTS/CCUS) eine Schlüsselrolle bei der Reduktion und Neutralisierung "schwer vermeidbarer" Emissionen spielen.

DemoUpCARMA ist ein Pilotprojekt, das die Machbarkeit und das Potenzial von zwei Pfaden und deren Hochskalierung aus verschiedenen Blickwinkeln evaluiert: (i) CO₂-Nutzung und dauerhafte Speicherung in Abbruchbeton in der Schweiz (CCUS) und (ii) CO₂-Transport und dauerhafte Speicherung in ein geologisches Reservoir in Island (CCTS).

Die Verwirklichung von CCUS und (grenzüberschreitenden) CCTS-Pfaden erfordert sowohl die Auseinandersetzung mit bestehenden als auch die Schaffung neuer Infrastrukturen, Wertschöpfungsketten, Geschäftsmodellen, Gesetze und Verordnungen. Darüber hinaus können Zielkonflikte, Nebeneffekte und die Kosten eine Vielzahl von Interessen betreffen. Deshalb ist die Einbindung von Interessengruppen in die Umsetzung von CCTS/CCUS sowohl aus normativen als auch aus instrumentellen Gründen notwendig. Mit dem hier vorgestellten Stakeholder-Mapping wollen wir die Grundlage für ein erfolgreiches und ganzheitliches Stakeholder-Engagement im Rahmen von CCTS/CCUS-bezogenen politischen Entscheidungs- und Implementierungsprojekten schaffen.

Zu diesem Zweck haben wir Stakeholdern-Positionen anhand eines Fragebogens, halbstrukturierter Interviews sowie Online-Recherche und informellem Austausch analysiert. Anschliessend haben wir die relevanten schweizerischen und internationalen Stakeholder in Gruppen eingeteilt (Forschungsfrage 1), ihre Perspektiven und Interessen untersucht (2 & 3) und Empfehlungen für die Einbindung der Stakeholder und die Entscheidungsfindung bei der Umsetzung von CCTS/CCUS in der Schweiz abgeleitet (4).

Unsere Ergebnisse skizzieren relevante internationale Stakeholder-gruppen und zeigen die Interessen und Einflussmöglichkeiten von dreizehn sich teilweise überschneidenden Stakeholder-Gruppen in der Schweiz auf. Wir diskutieren dabei nicht nur Chancen und Herausforderungen aus Sicht der Stakeholder, sondern auch ihren Blick auf massgebliche Rahmenbedingungen und (künftige) Einflussfaktoren im Hinblick auf einen möglichen Einsatz von CCTS/CCUS im industriellen Massstab.

Unsere Ergebnisse zeigen, dass es bisher eine relativ kleine und engagierte Gruppe von im Thema engagierten Akteuren in der Schweiz gibt. Diese Akteure teilen branchenübergreifend ein grundsätzliches Verständnis der Rolle und der Anforderungen von CCTS/CCUS-Pfaden in der Schweizer Klimapolitik. Die Prioritäten und Handlungsweisen in Bezug auf das Thema divergieren jedoch zwischen diesen Akteuren. Befürworter sehen keine Alternative zu CCTS/CCUS, um die Schweizer Klimaziele zu erreichen. Dahingegen wollen Beobachter und Bedenkenträger klare Nachweise sehen, dass CCTS/CCUS sowohl für den Klimaschutz als auch aus wirtschaftlicher Sicht sinnvoll ist. Eine Skalierung der Ansätze erfordert aus Sicht der Akteure regulatorische Klarheit und Business Cases sowie eine koordinierte Herangehensweise an die verschiedenen Teile der Wertschöpfungsketten von der Abscheidung bis zur Speicherung von CO₂. So kann die Henne-Ei-Problematik bezüglich voneinander abhängiger Investitionsentscheidungen aufgelöst werden. In einem nächsten Schritt erfordert die lokale Umsetzung eine frühzeitige Einbindung von weiteren, spezifisch betroffenen Gruppen und Organisationen, die bisher wenig im Thema aktiv sind.

Unsere Ergebnisse und die daraus abgeleiteten Empfehlungen können Institutionen und Projektentwickler*innen dabei helfen, proaktiv mit den relevanten Stakeholdern in der Schweiz und auf internationaler Ebene in Kontakt zu treten und dabei ihre dynamischen Interessen und Verantwortlichkeiten in Bezug auf CCTS/CCUS sowie die große Bandbreite an Vorwissen und Interesse innerhalb einzelner Stakeholder-Gruppen und Organisationen zu berücksichtigen.

1. Introduction

Authorship note: Parts of the introduction, including Section 1.2, focusing on DemoUpCarma and CCTS/CCUS in general were originally written by Dr. Irina Dallo for the report of Deliverable 5.6 (WP5, Subtask 2.7) and adapted here for this report.

All pathways to limit global warming to 2°C above pre-industrial levels and to achieve “net zero emissions”¹ require rapid decarbonization (IPCC, 2018, 2022). Since society will not be able to entirely eliminate carbon emissions (i.e., hard-to-abate sectors such as aviation and agriculture), the removal of CO₂ from the atmosphere is needed too (Ho, 2023). Thus, to achieve the climate goals by 2050 and limit global warming to 2°C, Carbon Dioxide Removal (CDR)² as well as Carbon Capture, Transportation, Utilization and Storage (CCTS/CCUS) must be fostered (Honegger, 2019; IPCC, 2018). CDR methods shall be used to remove already emitted CO₂ from the atmosphere and to store it permanently in safe places. In comparison, CCTS/CCUS should capture the CO₂ at for example industrial plants and either store it underground or in long-lived products. When CCTS/CCUS is applied to capture and store CO₂ of biogenic origin, CDR is achieved, i.e., as Biomass for Energy with Carbon Capture and Storage (BECCS).

There are various (research) efforts around the world to evaluate the potential of different CDR methods and CCTS/CCUS technologies, such as BECCS. Among these projects is the pilot project DemoUpCARMA, led by ETH Zurich. It aims to demonstrate the implementation and upscaling of two specific pathways leading to negative emissions (Figure 1):

- 1) CO₂ utilization and permanent storage in recycled concrete in Switzerland using a novel technology (Carbon Capture, Utilization and Storage, CCUS)
- 2) CO₂ transport and permanent storage in a geological reservoir in Iceland (Carbon Capture, Transport and Storage (CCTS)).

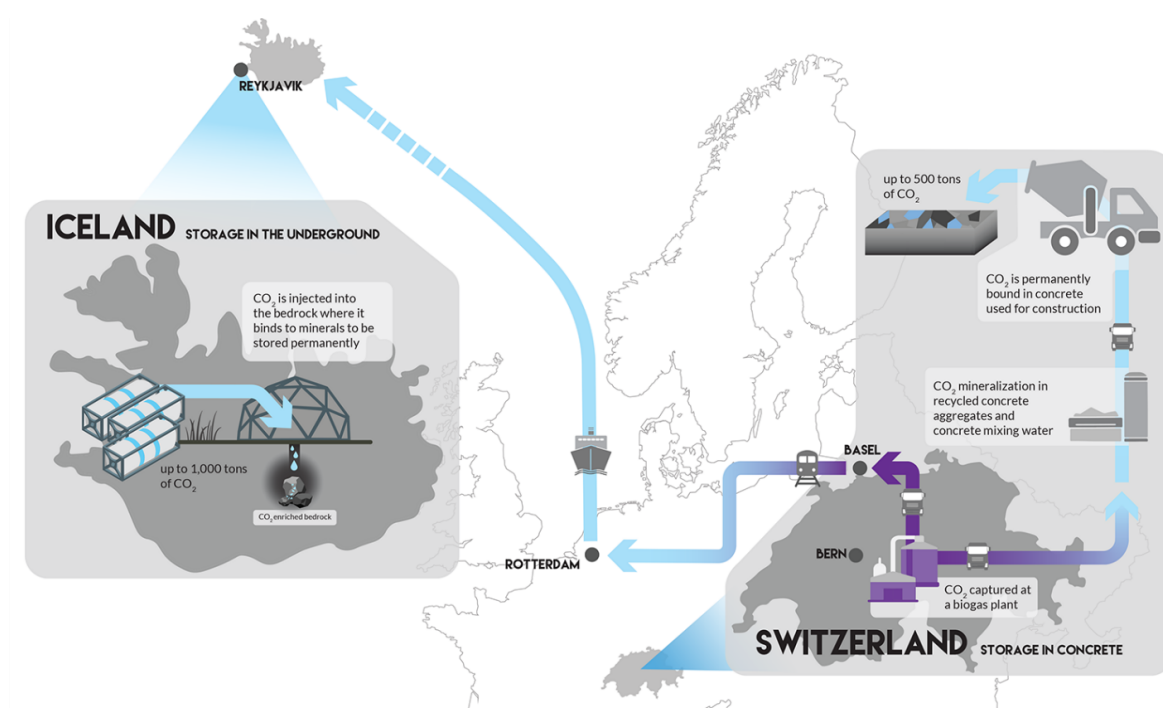


Figure 1: Infographic of the two pathways to reduce CO₂ emissions envisioned by DemoUpCARMA. Source: <https://demoupcarma.ethz.ch> (last accessed 15 Sep 2023)

¹ The greenhouse gas (GHG) emissions which are produced are also removed from the atmosphere; leading to a net balance of zero GHG emissions.

² In this report, we use the term CDR for human activities that remove CO₂ from the short carbon cycle and durably store it away from the atmosphere. We use the term “CDR methods” synonymously with the term “Negative Emission Technologies” (NETs), which is frequently used in reports and legislative texts in Switzerland.

The interdisciplinary research teams of DemoUpCARMA assess the optimal design of CCTS/CCUS pathways and their upscaling potential considering technological, economic, regulatory, political, and societal factors. The project is funded and supported by the Swiss Federal Office of Energy (SFOE) and the Federal Office for the Environment (FOEN), as well as ETH Zurich.

1.1 Objectives and Research Questions

This report specifically focuses on the mapping of stakeholders with relevance for the two pathways for CO₂ captured from Swiss point sources. The mapping includes both relevant stakeholder groups in Switzerland and key international stakeholders. Stakeholders' premises, interests and scopes of influence with regard to the two pathways are discussed alongside a discussion of determining factors and boundary conditions that could change dynamics in the future.

The potential implementation and upscaling of CCTS and CCUS for the mitigation of climate change requires systemic innovation, combining a coordinated approach between private and public actors with careful regulation and weighing of interests, and long-term funding commitments. The goal of this report is to lay the basis to facilitate such systemic innovation by providing answers to the following four questions:

- Q1. Who are relevant stakeholder groups for the implementation and upscaling of CCTS/CCUS in Switzerland, both (a) domestically and (b) internationally?
- Q2. Which premises do Swiss stakeholders have regarding the implementation and upscaling of CCTS/CCUS? Which opportunities, challenges, as well as determining factors and boundary conditions do stakeholders perceive?
- Q3. What are stakeholders' interests, scopes of influence, and levels of activity with regard to CCTS/CCUS?
- Q4. What recommendation can we make for policy makers, practitioners and researchers to effectively engage with relevant stakeholders around CCTS/CCUS?

To this end, we conducted interviews with individuals from across stakeholder groups, consulted publicly available communications and publications by stakeholders, and exchanged with stakeholders in formal and semi-formal settings such as workshops, working groups, webinars and networking events.

The novelty of our study is that stakeholder groups (Q1) and their premises (Q2), as well as interests and scopes of influence (Q3), have been examined with regard to the implementation of two very specific pathways for the capture and long-term storage of CO₂ in the context of Switzerland. This allowed us to derive recommendations (Q4) for stakeholder engagements based on literature and the findings from the stakeholder mapping. These recommendations are valuable for institutions responsible for regulating and implementing projects and thus engaging with stakeholders related to CDR methods and CCTS/CCUS.

1.2 Technical and Political Context

This section presents a general overview of the scientific background, as well as technical and political context of CCS and CDR in Switzerland, for readers who are not yet familiar with this context information.

In recent decades, greenhouse gas (GHG) emissions from human activities have increased, leading to a rise in global average temperature and, consequently, to severe consequences for natural and human systems (IPCC, 2022). To minimize these impacts, GHG emissions must be drastically reduced until 2050, primarily by ending the combustion of fossil fuels (IPCC, 2018). In addition, the Intergovernmental Panel on Climate Change (IPCC) report shows that the pathways leading to net-zero emissions by the mid-century also rely on the use of CDR methods leading to negative emissions, but also CCS technologies (Honegger, 2019; IPCC, 2018).

Carbon Capture (CC) is a process to capture CO₂ before it enters the atmosphere and to either use it (CCU) or to store it typically in geological formations (CCS). CC always implies CO₂ separation, compression, transport, and storage/utilization (Nick & Thalmann, 2021). In general, there are three techniques to separate CO₂ from flue gases. The CO₂ can then be transported by pipeline, ship, rail, or truck to be either processed or stored underground (Nick & Thalmann, 2021). If CCU leads to durable storage of the utilized carbon outside the atmosphere, it qualifies as CCUS. Utilizations of CO₂ potentially leading to storage include mineral carbonation (Valluri et al., 2022) and enhanced oil recovery (Nick & Thalmann, 2021). The utilization of CO₂ as food additives (Valluri et al., 2022) or for CO₂-based fuels (Simons et al., 2021) does not lead to storage of carbon outside the atmosphere.

CCTS and CCUS can contribute to the mitigation of climate change in two ways. They lead to reduced emissions if the captured CO₂ is of fossil³ or geogenic⁴ origin. For CO₂ of biogenic origin, CCTS/CCUS can produce negative emissions and thus qualify as CDR. The reason is that the carbon in biomass has been removed from the atmosphere via photosynthesis before. CDR methods that include CC from biogenic sources are called bioenergy with carbon capture and storage (BECCS) or biomass carbon removal and storage (BiCRS) (Airfix, 2023; Sandalow et al., 2021).

Switzerland aims to be climate neutral by 2050. The Swiss Federal Council, Switzerland's government, stated in its report that the Paris climate goals and the Swiss climate goals for 2050 can only be met by combining strict decarbonization with the deployment of CDR and CCS in the order of magnitude of several millions of tons (Mt) of CO₂ per year (FOEN, 2020). The Net Zero goal is part of the Swiss Climate and Innovation Act (KIG), as well as the Swiss Energy Strategy 2050, with which Switzerland should be able to maintain the high energy supply standard and to reduce the energy-related environmental pollution. In order to achieve these goals, and thus to comply with the Paris Climate Agreement, various efforts were defined (Figure 2). Two of these efforts are more stringent measures: i) reduction of the energy consumption and CO₂ emissions and ii) compensation for the residual emissions through CCS and CDR.

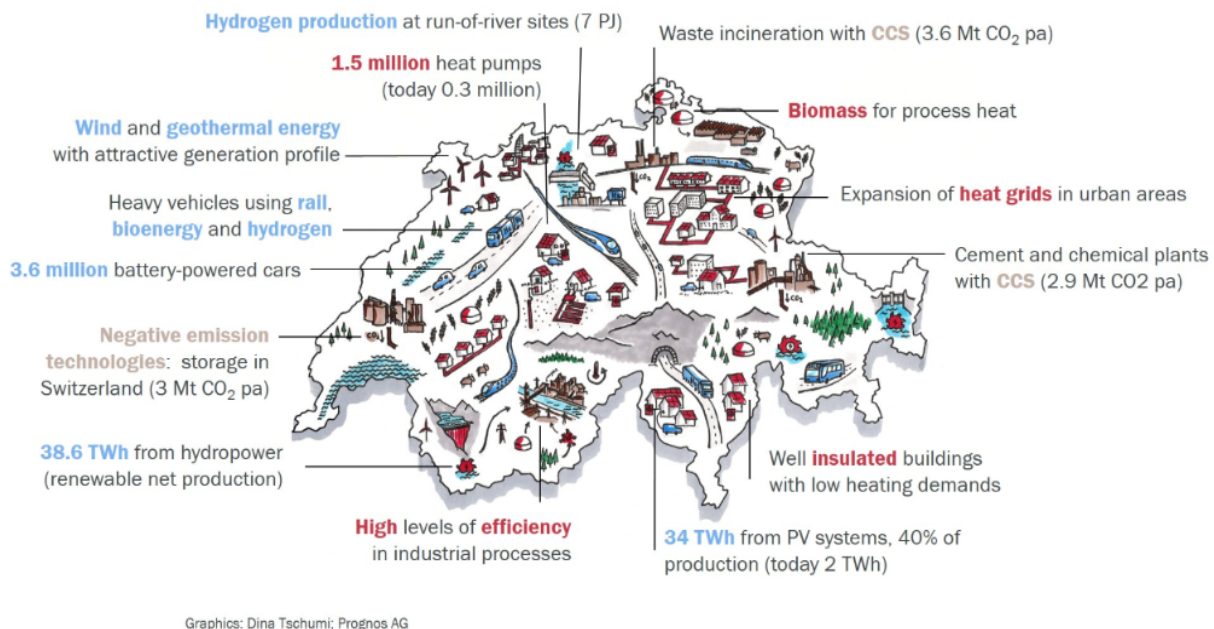


Figure 2: Objectives for a climate-neutral Switzerland by 2050. Source: Swiss Energy Strategy 2050.

³ Fossil emissions refers to CO₂ emissions, i.e., from the combustion of fossil coal, oil or gas.

⁴ Geogenic emissions refer to direct process emissions of CO₂ in the cement production, especially from the initial calcination reaction. The largest share of CO₂ emissions from cement production in Switzerland are geogenic.

Relevant Swiss point sources of CO₂ where CC could be applied are:

- Cement plants,
- Waste-to-energy plants,
- Waste water treatment plants,
- Biogas plants,
- Wood-fired power plants,
- Chemical and other industry.

The main focus in DemoUpCARMA with regard to a potential upscaling of CCTS/CCUS are the cement, waste-to-energy and waste-water sectors, because they have large point sources frequently associated with hard-to-abate emissions, but also with the potential to achieve CDR:

The 29 Swiss waste-to-energy plants cause about 5% of Swiss GHG emissions and emit more than 2 Mt CO₂ per year from the incineration of waste of fossil origin, mainly plastic⁵. In addition, similar amounts of CO₂ are released from the combustion of biomass, which is not listed in the GHG inventory. Integrating a CC unit in a waste incineration plant can therefore both reduce emissions that are difficult to avoid and help to achieve CDR (BECCS, through biomass content). Currently, the implementation of CO₂ capture in some municipal waste incineration plants is being examined. In March 2022, the federal government and the operators of waste-to-energy plants in Switzerland signed a renewed agreement⁶ to reduce CO₂ emissions in the sector. The operators committed themselves to commissioning at least one CC unit by 2030, with a minimum nominal capacity of 0.1 Mt of CO₂ per year.

In 2019, the six cement plants in Switzerland released a total of approximately 2.9 Mt CO₂ with a negative trend since 1990 reported by the industry (cemsuisse, 2021). Of these 2.9 Mt, 1.7 Mt are geogenic, 0.8 fossil and 0.2 biogenic. The Swiss cement industry is registered in the Swiss Emissions Trading System (ETS). According to cemsuisse (2021), CCS is required to reach net zero emissions for the sector, with CCS potentially contributing to 70.9% of emission reductions compared to 2019.

If implemented at large scale, the two CCS pathways demonstrated in the DemoUpCARMA project require both the integration of novel technologies in existing value chains, but also new infrastructure, funding mechanisms and regulations. This implies potential synergies and co-benefits but also trade-offs and side effects. In this context, the implementation of CCTS/CCUS affects and involves multiple sectors in Switzerland and interest groups, including the energy, waste, cement, construction and logistics sectors. At the same time, policy makers, regulators, funders, civil society organizations, locally affected residents and the general public have relevant interests and roles to play. Since the CCTS pathway involves the cross-border transport and storage of CO₂, it cannot be realized without international cooperation and the integration in European efforts. Also, international regulators, service providers, investors and buyers of CDR-related credits can potentially influence the implementation and financing of CCTS and CCUS in Switzerland and globally.

1.3 Stakeholder Engagement

With this section, we introduce scientific findings related to stakeholder positions and engagement in the context of CCTS/CCUS and CDR, further informing our method and analysis (Q1-3), as well as the recommendations (Q4) presented in the following sections.

⁵ Sources: FOEN (<https://www.bafu.admin.ch/bafu/de/home/themen/klima/zustand/daten/treibhausgasinventar/industrie.html>) and VBSA (<https://vbsa.ch/wp-content/uploads/2020/01/CO2-Report/co2-emissionen-aus-kehrichverwertungsanlagen-kva.html>)

⁶ <https://www.bafu.admin.ch/bafu/en/home/topics/climate/info-specialists/reduction-measures/sector-agreements/agreement-waste-treatment.html>

In research, development and implementation of CCTS/CCUS and CDR in general, societal aspects must also be considered and possibly addressed for various reasons: First, the adoption of CCTS/CCUS technologies depends on various factors such as national frameworks and policies, which must be co-created by all relevant stakeholders. To ensure a sustainable and on the long-term successful implementation of CCTS/CCUS and other CDR methods, it is key to ensure procedural justice and societal support. This can be strengthened with public participation and stakeholder engagement, including transparent policy deliberation and design processes (Honegger et al., 2022). Second, public acceptance is critical because, as we have seen with other technologies such as geothermal power plants, public opposition can hinder projects (Stauffacher et al., 2015). Third, the public in different countries will potentially have a say on whether or not a project should be implemented and therefore needs understandable and clear information to make scientifically informed decisions. While the report of Deliverable 5.6 focuses on the broader public acceptance, we here examine the stakes and premises of institutional stakeholders and specific interest groups.

Germany and the EU, among others, are currently in a “formative phase” for CCTS/CCUS- and CDR-related policy (Boettcher et al., 2023). The same can be said for Switzerland, with policies and regulation under development within the frameworks of the national climate strategy and the KIG approved in the June 2023 referendum.

When engaging with stakeholders in the formation phase, integrating the needs and agendas of all diverging positions can be challenging. The framing of the topic can have an impact on the discourse: Whether we use the term CCS or the term CDR interacts with other discourses and knowledge. In their analysis of stakeholder discourses, Cox et al. (2020) noted that the perspectives of informed stakeholders on CCS “tend to focus on a techno-economic narrative of whether we could implement such systems, whereas these on [CDR] seem to raise more ethical and normative narratives of whether we should.”

Next to the framing, so-called “place factors” can influence (public) acceptance of CCS projects (Rothkirch & Ejderyan, 2021). Place factors identified for CCS include, among others:

- Population density
- High infrastructure development
- Whether infrastructure is developed in areas that are already an industrial site or not
- Environmental impacts
- (Lack of) legislation for CCS / legislation barriers
- Good/bad relationships with industry and project developers

The assessment of the specific context of a project, including place factors, can help define the requirements, level and target groups of stakeholder engagements.

For Germany, Boettcher et al. (2023) found a lot of activities in policy making and advocacy with regard to CDR happening in parallel. The authors identified five predominant stakeholder positions with regard to CDR policy between precaution, pragmatism and innovation (Figure 3):

- Agenda-setting innovator,
- Pragmatic integrationist,
- Utilitarian solutionist,
- Precautionary gatekeeper,
- Responsible information provider.

These “ideal types” of positions differ in their rational towards CDR and preferred (political) measures, as shown in Boettcher et al. (2023, Table 1).

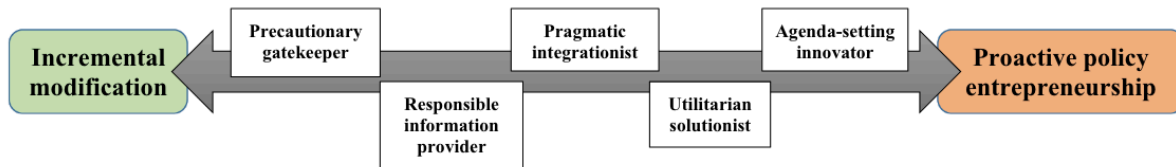


Figure 3: Conceptual overview of speaker positions on the continuum of two different types of CDR policy integration. Source: Boettcher et al. (2023)

The speaker positions identified by Boettcher et al. (2023) relate both to the premises of stakeholders (Q2) and to their interests, scopes of influence, and levels of activity (Q3) that we assess here.

The studies referenced above provide valuable guidance for stakeholder analysis and stakeholder engagement in the fields of CCTSCCUS. In the following sections, we use the concepts as reference points by which stakeholders' perspectives around the particular pathways demonstrated with DemoUpCARMA can be integrated.

2. Methods

2.1 Stakeholder Mapping Approach

A number of different concepts and methods for stakeholder analysis and stakeholder mapping circulate across disciplines. According to Reed et al. (2009), approaches to stakeholder analysis can be differentiated by their rationale, typology and methods (Figure 4).

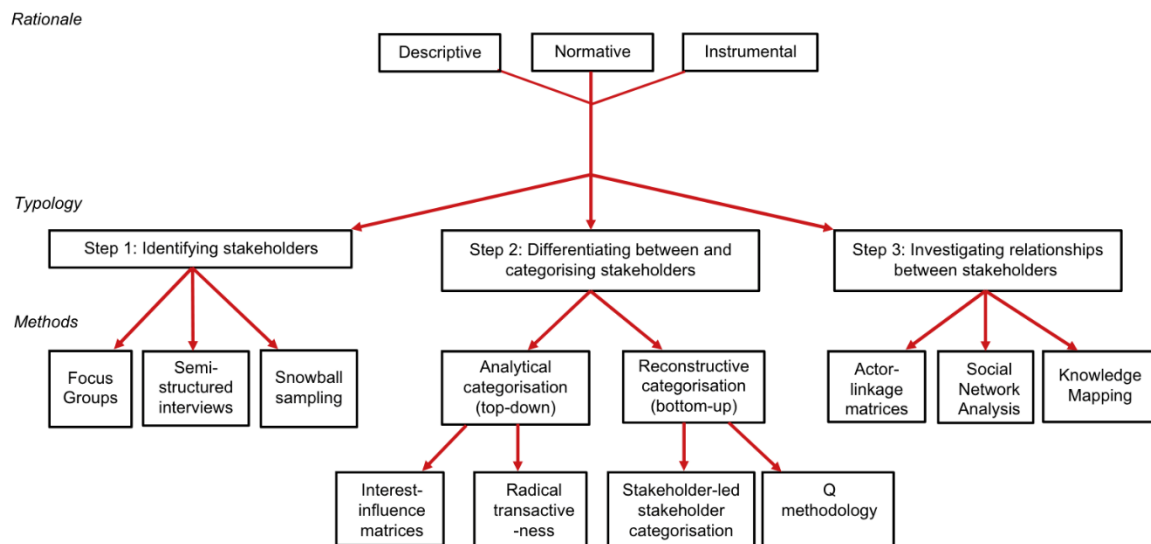


Figure 4: Schematic representation of rationale, typology and methods for stakeholder analysis. Source: Reed et al. (2009). For details on the methods consult the original study.

For the mapping and analysis in this study (Q1-3), we follow a mainly descriptive and instrumental approach that is made explicit along Reed et al.'s overview of stakeholder analysis approaches (Figure 4).

The **rationale** of the stakeholder mapping and analysis conducted here is predominantly *instrumental*, aiming to assess the societal context and conditions of a potential upscaling of CCTS/CCUS (Q1-3). This includes a descriptive analysis (Q1), as a necessary precursor to both normative and instrumental analyses. The *instrumental* component to the analysis is reflected

especially in the choice of relevant stakeholder groups and in the discussion of influence factors related to a potential upscaling of the two technological climate mitigation pathways demonstrated and assessed in DemoUpCARMA. For this, we defined a relevant stake qualitatively by (a) level of interest and/or (potential) affectedness and (b) relevant scopes of influence (power). *Normative* aspects are not the focus of this study. However, the consideration of affectedness has a normative component, as well as an instrumental one: The engagement with potentially affected stakeholders is relevant for ethical reasons and can at the same time play a pivotal role in the societal perception of and support for policies and implementation projects (Honegger et al., 2022; Rothkirch & Ejderyan, 2021).

The steps of **typology** and **methods** were implemented as following:

For the *identification of stakeholders* (step 1), we combined snowball sampling with semi-structured interviews. For the snowball sampling, we gathered information on relevant stakeholders with the insights from a survey among DemoUpCARMA consortia members, participation in stakeholder workshops and informal exchange. Furthermore, interviewees were asked who else should be considered as relevant stakeholder. For the *differentiation between and categorization of stakeholders* (step 2), we combined an analytical categorization with elements of bottom-up categorization to fill the gaps. Due to the high heterogeneity in interest within many organizations, initial attempts to construct an interest-influence matrix with quantitative axis were later replaced by a qualitative categorization (Figure 5) along the main interests in and the means of stakeholder to influence the topic. An in-depth analysis of the *relationships between stakeholders* (step 3) was out of scope for this study. However, the mapping conducted here provides the basis of more detailed relationship assessments that become necessary for each specific case of CCTS/CCUS implementation, considering local and sector-specific relationships as well as place factors.

2.2 Data Acquisition and Analysis

We conducted 17 semi-structured interviews with Swiss stakeholders. The interview questions can be found in Table A4 in the Annex. The interviews were complemented with desk research, a joint questionnaire (Table A5) answered by twelve members of the consortia and two federal offices, insights from the DemoUpCARMA workshops; as well as exchanges with stakeholders in Switzerland, Iceland, and other European countries. Synergies were achieved with the Swiss Carbon Removal Platform (CDR Swiss)⁷, a multi-stakeholder platform initiated and lead by the Risk Dialogue Foundation, and the research project Carbon Dioxide Removal Options: Policies and Ethics (CDR-PoEt)⁸. As part of CDR-PoEt, Risk Dialogue conducted topical interviews with stakeholders in Iceland and co-facilitated science-stakeholder workshops on CDR with German and European stakeholders. The synergies between the projects and the knowledge gain and transfer between the projects contributed substantially to map key stakeholders in Switzerland and internationally and gain insights into diverse stakeholder perspectives, both in formal and informal settings.

In the qualitative analysis, we focused on identifying (Step 1 in Figure 4) and qualitatively grouping relevant stakeholders (Q1), and assessing their premises (Q2) and positions (Q3) with regard to the demonstrated CCTS and CCUS value chains and their potential upscaling, as well as their level of knowledge and information and engagement/communication needs to answer Q4 (all part of step 2 in Figure 4). As an instrumental focus point, stakeholders were asked whether they see any determining factors and boundary conditions that could potentially change their interests or scopes of influence in the future (Q2). Such “tipping points” could potentially enable, accelerate or block the implementation and upscaling of the two pathways.

⁷ <https://www.carbon-removal.ch>, last accessed 20 Sep 2023

⁸ <https://cdrterra.de/en/consortia/cdr-poet>, last accessed 20 Sep 2023

3. Results

We identified stakeholders with relevance for both current endeavors related to CCUS and CCTS and a potential industrial scale implementation of these pathways in Switzerland. We defined a *relevant* stake qualitatively by (a) level of interest and/or affectedness and (b) power of influence. We found that the level of interest often varies within individual stakeholder groups and even within organizations. We applied two qualitative categorizations to map differences in interest and influence of stakeholders:

- A qualitative assignment of **stakeholder groups** relevant for the implementation and scaling of CCTS/CCUS in Switzerland (Q1); and
- An assessment of stakeholders' **interests** and **scopes of influence** (Q2), as well as **premises** (Q3) towards a potential upscaling – identifying unified and diverging attitudes.

Chapter 3 is divided into three parts. In Section 3.1, an overview of the stakeholder groups is provided (Q1a) with a focus on Swiss stakeholders. A more differentiated analysis of stakeholder positions in Switzerland is discussed in Sections 3.2 (Q2 & Q3). Key international stakeholder groups are introduced in Section 3.3 (Q1b).

A list of exemplary stakeholders in Switzerland mapped to their primary category is provided in Table A1 in the Annex, while international stakeholders with potential relevance for the Swiss context are listed in Table A2.

These results guided the development of differentiated **recommendations** (Q4) for communication and stakeholder engagement (Eberenz and Dallo et al., submitted).

3.1 Stakeholder Groups (Q1)

The realization of CCUS and (cross-border) CCTS pathways require both the engagement with existing and the creation of novel infrastructures, value chains, business models, policies, laws and regulations. Therefore, relevant stakeholders include a broad range of organizations and interest groups from private and public sectors, as well as the civil society (Figure 5).

We categorized relevant stakeholders into thirteen groups in Switzerland and additional groups abroad. Some stakeholders fall into multiple groups, potentially raising questions of conflicting or unclear roles and responsibilities:

- CO₂ point sources,
- Challenge owners,
- Policy makers and regulators,
- Associations,
- CCTS/CCUS solution providers,
- CCUS product users,
- CCU advocates,
- Investors and buyers of CDR (or CO₂ credits),
- Research,
- Local or specifically affected groups and sectors,
- Political parties,
- Civil society,
- The public.

More information on how the stakeholder groups were represented in the interviews can be found in Table A3 in the Annex.

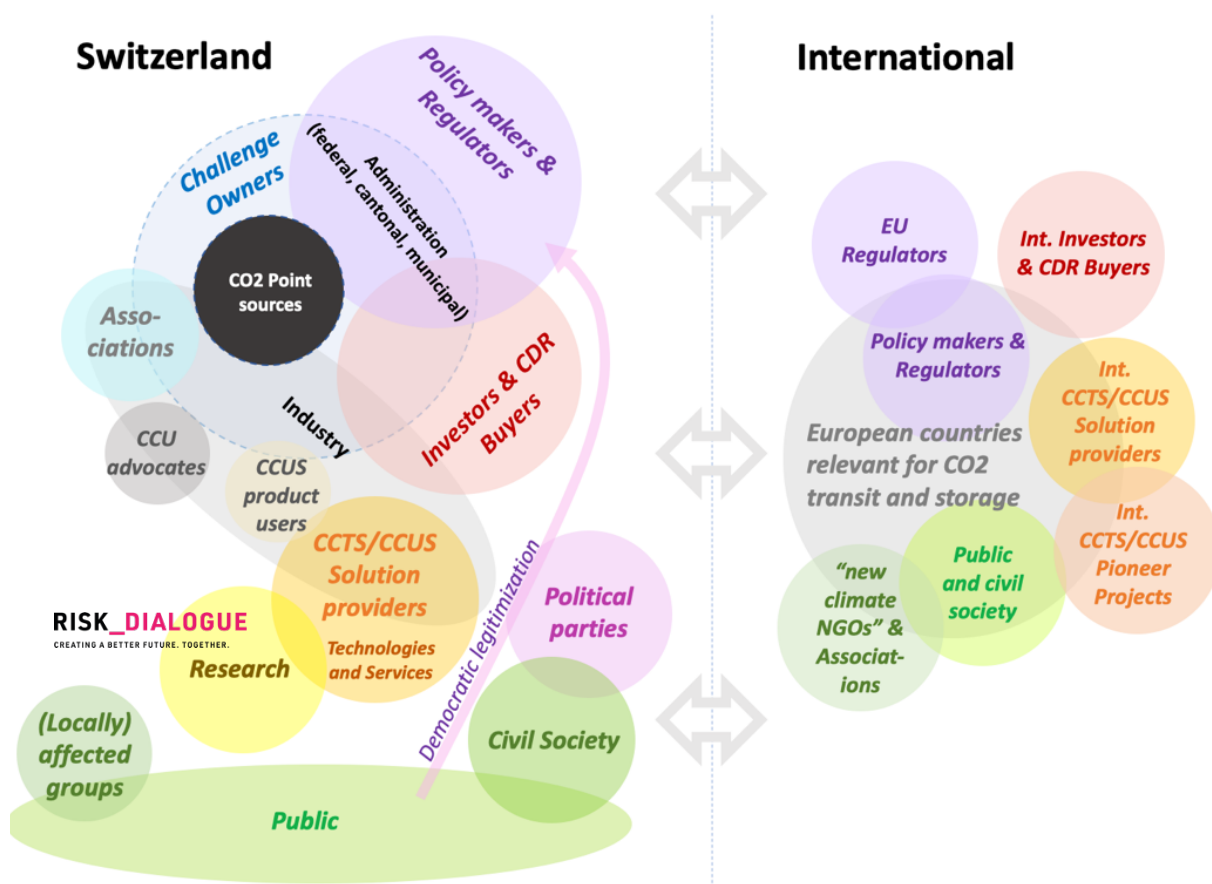


Figure 5: Stakeholder map for CCTS/CCUS (Venn Diagram): Schematic mapping of stakeholder groups and their overlaps. The most relevant groups for the implementation and scaling of CCUS and cross-border CCTS in Switzerland (left) cluster around the CO₂ point sources (black). Key international stakeholder groups are shown in the right panel. The purple arrow illustrates democratic legitimization processes as a direct line of influence connecting the public with policy makers and regulators. Other lines of influences between stakeholder groups exist but are not shown. The size and color of the bubbles have only a design function (The size does not reflect any parameter such as level of influence or power of influence).

Example stakeholders per group are listed in Table A1 in the Annex. While most groups are self-explanatory from that list, the first two, “point sources” and “challenge owners” require a bit more explanation:

CO₂ point sources (black bubble in Figure 5) are, strictly speaking, not a stakeholder group per se, but represent the condensation nuclei of the stakeholder mapping. Their fossil, geogenic and biogenic CO₂ emissions are the single reason to think about CCTS/CCUS in the first place (see Introduction). The capture and storage of CO₂ from for example cement and waste-to-energy plants is at the core of the challenge.

Challenge owners (dark blue bubble) represent a meta category, entailing all stakeholders with a direct responsibility for or a political mandate related to CO₂ point sources. Challenge owners include the privately and publicly owned companies owning/operating CO₂ point sources, as well as federal, cantonal, and municipal governments and administration with a mandate to achieve emission reduction within their jurisdiction. Further, political entities can also consider buying and/or retiring carbon dioxide removals (CDR) results from bioenergy-related CCTS/CCUS activities within or outside their jurisdiction to reach their own net-zero targets.

Figure 5 can be read as a Venn Diagram, illustrating the most prominent overlaps of stakeholder groups both within Switzerland and internationally. Overlapping areas indicate the multiple roles some key stakeholders can inhabit. For example, political entities and their administration (e.g., cantons) can at the same time be policy makers and regulators, both “challenge owners” for CO₂-

point sources and point of contact for authorization procedures within their jurisdiction. The many overlaps in this cluster illustrate the entangled situation of stakeholders around CO₂ point sources – with partially unclear responsibilities regarding the various parts of a value chain from capture to storage of CO₂. This leads to chicken-and-egg problems regarding interdependent investment decisions. Some of the more remote overlaps between stakeholder groups are not shown in Figure 5. For example, public administration can also be a CCUS product user via public procurement in the construction sector.

Not all stakeholders are relevant for both pathways. Table 1 sorts (sub-)groups of key stakeholders by pathway. Stakeholders from the construction sector are specific to the CCUS pathway. For CCTS, key international stakeholders include European regulators both from the EU and individual countries, as well as providers of logistics and CO₂ storage solutions. As mentioned above, the stakeholder groups shown in Figure 5 are not mutually exclusive: There are overlaps and some key stakeholders can be assigned to two or more groups. With this in mind, the mapping allows for a differentiated discussion of stakes to guide the selection of stakeholders to be involved in research, implementation or policy making processes.

Stakeholder (Sub)groups by Pathway		
Both Pathways	Storage in Concrete in Switzerland (CCUS)	Storage in Geological Reservoirs (CCTS)
- Point source owners and operators - Policy makers and politicians - Regulators - Administration of canton/municipality with relevant CO₂ point sources in their jurisdiction - Solution providers - Research - CDR buyers and investors - Civil society and public - CCU advocates	- Small and medium point sources (e.g., biogas, wastewater treatment) - Concrete carbonization solution providers - CCUS product users (e.g., in the construction sector) - Regulators (e.g., standards for materials)	- Medium and large point sources (e.g., cement, waste-to-energy) - Federal and cantonal policy makers and regulators - European regulators - Logistics and storage solution providers (Europe and CH) - Industry associations of emitters - Administration of cantons and municipalities with potential storage sites - Local stakeholders and residents around infrastructure, transit and storage sites

Table 1: (Sub-)groups of stakeholders with relevance for both pathways (left column), and specifically for storage in concrete in Switzerland (CCUS, middle column) and for storage in geological reservoirs abroad or domestically (CCTS, right column). All relevant stakeholder groups in Switzerland as well as selected key European stakeholders for CCTS are listed. Based on interviews and informal exchange with stakeholders. Lists of stakeholders are provided in Table A1 (Switzerland) and A2 (internationally) in the Annex of this report.

It is rather specific for CCTS/CCUS that some of the key stakeholders are part of multiple groups, thus holding multiple stakes at once, while at the same time not all responsibilities are yet clearly distributed among challenge owners. This constellation is discussed in more detail in the following sections. An in-depth analysis of lines of influence that are specific to the CCTS/CCUS topic was out of scope of this study.

Stakeholders from different groups, but also within each group, influence each other in various ways that can be more formal or informal. Typical explicit activities to exert influence include public votes and political motions, political mandates and regulation, sector agreements, policy advocacy and lobbying, stakeholder engagements and international agreements. In the following section, a closer look is taken at premises and activities (see also Tables 2 and 3).

3.2 Positions by Stakeholders in Switzerland

There are notable differences between these groups in the scopes of influence on the implementation and upscaling of CCTS/CCUS pathways. Some stakeholders have a double role, for example public administration involved both as regulator and challenge owner. For those not directly involved, the topic often remains abstract until they are directly affected by an implementation or asked to get involved. In Section 3.2, we examine the most relevant identified stakeholder groups for Switzerland, summarizing their premises (Q2), as well as interests and scopes of influence (Q3).

3.2.1 Premises (Q2)

The following aspects were discussed with stakeholders in the interviews to get an understanding of their premises regarding the CCTS and CCUS pathways (Key findings are summarized in Table 2 below):

- General technical and scientific understanding of the pathways,
- The priority and potential role assigned to CCTS/CCUS for the mitigation of climate change in Switzerland,
- Perceived opportunities and challenges of implementation,
- Potential systemic determining factors and boundary conditions that could enable or block the operationalization and upscaling of the two pathways in the future.

The interviewees represent a relatively small but cross-sector group of individuals and organizations in Switzerland who are pro-active in the topic. This means that the data is mainly based on the perspectives of individuals highly engaged in the topic. Overall, we found that all stakeholders in Switzerland who are active and/or outspoken on CCTS and CCUS share the same general understanding. We found no disagreement or even contradictory attitudes regarding the basic understanding of the processes and their potential role for Swiss climate mitigation. However, the importance of and assigned priority to CCTS/CCUS differs between stakeholders. Not all stakeholders mentioned the same opportunities, challenges and determining factors and boundary conditions. But there were common themes between stakeholders and no mutually exclusive views.

General understanding:

For both pathways, the interviewees showed an at least basic understanding of the processes. This result is not surprising as we focused on interviewees who are either active advocates of the topic or experts in related fields. In contrast, there is a relatively low familiarity with the pathways found in the general public (see Deliverable 5.6 of DemoUpCARMA). The interviewees agreed that CCTS and CCUS pathways can potentially contribute to the mitigation of climate change both by reducing hard-to-abate fossil and geogenic emissions, e.g., from the burning of plastic waste or chemical processes in the cement production. Also, they acknowledged the potential to produce CDR, contributing to negative emissions, when biogenic CO₂ is captured and stored in the process (e.g., from the burning of organic waste or wood). At the same time, the unchanged necessity to reduce emissions drastically across sectors was mentioned by several stakeholders. The implementation of CCTS/CCUS should not be used as an excuse to deter the phaseout of fossil fuels. They argued that mitigation measures that can be implemented more cost efficient than CCTS/CCUS should happen undeterred in parallel to any efforts to scale up CCTS/CCUS.

Perceived opportunities, challenges and "systemic tipping points":

Table 2 gives a more detailed overview of the opportunities, challenges and determining factors and boundary conditions perceived by stakeholders from Switzerland for both pathways.

Premises by Pathway			
	Both pathways	Storage in Concrete in Switzerland (CCUS)	Storage in Geological Reservoirs (CCTS)
Perceived Opportunities	- Potential to reduce hard-to-abate emissions - Potential to produce CDR (negative emissions) - Integration of capture in existing value chains - More energy-efficient than DAC/DACCS - No additional competition for primary use of biomass and land	- Local and decentralized solution - Suited for small point sources - Integration in operative value chains and infrastructures - Innovative solution as economic opportunity - Innovation potential in processes and tapping into other waste streams	- Large potential for avoided emissions and CDR / negative emissions (Megatons of CO₂/year) - Suited for large point sources - Efficient solution for large quantities of CO₂
Perceived Challenges	- Lack of planning security while needs to plan for decades - Space requirement of capture module in existing plants - High and partially uncertain investment and operation costs - Energy penalty of CO₂ capture - Air pollution requirements could increase costs of capture - Risk to international competitiveness - Potential punishment for early-movers (competitive disadvantage)	- Limited capacity of pathway / not attractive for large point sources - Restrictive quality standards for concrete - Competitive prices in the construction sector - Carbon accounting: CO₂ absorbed in carbonization had been released when the cement in the concrete was produced in the first place - Risk of greenwashing in the construction sector	- Large new infrastructure and investments needed "Chicken-and-egg problem" regarding long-term investment decisions along pathway - International dependencies - International competition for CO₂ storage - Creation of an entirely new carbon management industry and infrastructure / risk of lock-in - Build-up of CO₂ infrastructure could slow down disassembly of fossil gas infrastructure - Local acceptance (e.g., storage)
Determining factors and boundary conditions	- Regulation and subsidies providing planning security for investments - Investors from Switzerland - Iterative upscaling, starting with small- & medium-size CC projects⁹ - Presence of successful pilot and pioneer projects to learn & showcase feasibility, costs & side-effects - High and legally binding CO₂ price / "painful" price signal from the ETS - Security of long-term supply for raw materials to justify investments for cement plants - Long-term security of supply of renewable energies - Carbon Border Adjustment Mechanism (CBAM) for cement import - Political will & - Public perception & support - Acceleration of climate change and impacts from extreme events	- Operationalization as part of concrete recycling value chain (achieved in Switzerland by 2023¹⁰) - Revision of quality standards for concrete, permitting use of mixes including carbonated demolition concrete - Public procurement creating demand for CCUS materials - Innovation in wet-chemical carbonization processes	- Coordinated approach on logistics / CO₂ hub - Decision for CO₂ storage site(s) and/or geographical "exit point" for CO₂ export - Nationally harmonized pipeline regulation - Timely infrastructure for train/ship transport - Reliable cost figures¹¹ & timelines for transport & storage - Capture obligations - Fair financing - EU and CH regulation streamlined, e.g., for CO₂ specifications - Clarity on natural gas phase-outs for transition of gas infrastructure - Clarity on potential geological storage in Switzerland - International CO₂ storage obligation

Table 2: Opportunities, challenges and determining factors and boundary conditions perceived by stakeholders from Switzerland for both pathways (left column) The center column lists aspects that are specific for storage of captured CO₂ in Concrete in Switzerland (CCUS). The right column lists aspects that are specific for storage of captured CO₂ in geological reservoirs (CCTS). Based on interviews and informal exchange with stakeholders.

⁹ for example planned CCS at Zurich's sewage sludge treatment plant Werdhölzli (25'000 tCO₂/year): <https://www.stadt-zuerich.ch/ted/de/index/departement/medien/medienmitteilungen/2023/mai/230526a.html> (last accessed, 11 Sep 2023)

¹⁰ See for example: <https://www.baublatt.ch/baubranche/co2-in-abbruchbeton-speichern-neustark-gibt-mit-grossanlage-gas-34585> (last accessed, 11 Sep 2023)

¹¹ Detailed cost estimates for the CCTS pathway were provided in a study mandated by the Swiss FOEN in 2023 (BAK Economics AG & Deutsche Energieagentur dena, 2023)

The difference in potential capacity is one of the main differences between CCUS and CCTS, with a strong impact on the level of interest of the challenge owners. Because of its limited capacities, the storage of CO₂ in concrete in Switzerland (CCUS) is of limited interest on the long-term for the operators of large CO₂ point sources (e.g., cement and waste-to-energy plants). However, the CCUS solution is attractive for smaller-scale capture projects. What makes CCUS attractive are the smaller infrastructure requirements and successful operationalization compared to the CCTS pathway.

Many of the determining factors and boundary conditions mentioned relate to the long investment cycles of decades and planning security required to make investment decisions. To enable decision-making, challenge owners see both clear regulations, a national coordination of efforts (e.g., for building a CO₂ transport network and the decision for storage sites), as well as international integration. In parallel, many stakeholders emphasized the importance of pilot projects at-scale and to move step-by-step from small-scale capture to megaton-projects and learn on the way.

Pilot projects are and can be done without complete clarity on costs and regulations, as long as they are de-risked and supported across stakeholder groups. Like this, successful pilot projects can help reduce uncertainties and accelerate implementation.

Many interviewees further highlighted the role of both private and public institutions in financing and de-risking the transition. While there are diverging perspectives on how the responsibilities and agency is distributed among key stakeholders, interviewees agreed that roles and responsibilities should be better coordinated and clarified to increase planning security for each individual agent. There are also other factors that influence investment decisions. For example, the cement industry strives for securing the long-term supply in raw materials for their cement plants to render an investment in CO₂ capture economically viable.

For the storage in demolished concrete (CCUS), one critical tipping point has already been reached by 2023: The value chain has become operational end-to-end and is ready for upscaling in Switzerland. Furthermore, single solution providers are already expanding to European markets.

3.2.2 Interests and Scopes of Influence (Q3)

An overview of interests and scopes of influence by Stakeholder group in Switzerland is provided in Table 3 below. Here, we discuss the findings and their key implications:

Interests: Priorities and Responsibilities

As to be expected from the different stakes and mandates of the stakeholder groups, there are variations in emphasis on interests, concerns and the priority of getting active in the topic. We also found differences in emphasis of trade-offs and requirements for an upscaling between and within stakeholder groups. Both the shared understanding and the different emphasis are echoed in the interviews, as well as in public statements and publications by stakeholders on the topic.

Stakeholders' premises on regulation and who should finance what diverge and are strongly guided by individual interests. Here, the roles and responsibilities of private actors and public entities on all federal levels require clarification, especially with regard to CCTS.

All interviewees perceive both pathways as technological solutions that can be added to existing value chains. In this framing, CCTS/CCUS can be implemented without transformative impact on the respective value chains that produce the CO₂ in question. On the one hand, this is seen positive by many interviewees who do not perceive a transformation leading to a decarbonization of the waste and the construction sectors as realistic. Furthermore, challenge owners have a clear idea how they can have an impact by implementing CCTS/CCUS but do not see a lot of agency for themselves in promoting more systemic transformations. For example, the Center for Sustainable Use of Waste and Resources (ZAR) states on its website: *"Waste avoidance and recycling are not contradictory to CO₂ capture in waste recycling plants. In order to achieve a sustainable, climate-friendly way of dealing with our goods, it is imperative to have both."*¹²

On the other hand, some interviewees from the civil society, policy making and administration cautioned that transformative efforts should not be neglected. They pledged for more imaginative and courageous ideas for decarbonizing the affected sectors with a focus on societal and ecological co-benefits. Transformative approaches mentioned were more stringent circular economy and the substitution of cement as a building material. On another note, one interviewee pledged for considering CCU as an alternative, more circular, pathway in using captured CO₂. The current exchange on the topic in Switzerland is mainly in expert circles with participants advocating for a high priority and potential role of CCTS/CCUS. Examples are the national working group on CCS and NET hosted by the FOEN and workshops conducted in the scope of research and pilot projects. However, as implementation and upscaling become more tangible, a broader debate with precautionary gatekeepers stepping up can be expected. The stakeholder interviews suggest that cautionary positions could be taken both by civil society actors and advocates of alternative mitigation pathways. Deterrence in the progress towards emission reduction targets could potentially spark a more critical debate around priorities and moral hazard in climate policy and action.

Scopes of Interest

Stakeholders can exert power in formal and informal ways. Based on statements by stakeholders, we identified key scopes of influence as well as example activities by stakeholder. The findings can be found in Table 3 (middle and right column).

¹² Source: <https://zar-ch.ch/zar/kompetenzenprojekte/co2-kompetenzzentrum/>, last accessed 11 Sep 2023. Translated using DeepL.com.

Interests and Scopes of Influence by Stakeholder Group in Switzerland			
Group	Main interests	Key scopes of influence	Example activities
Emitters/ Point source operators & owners	- Planning security - Fair conditions of competition - Economic viability - CO₂ transport and storage solutions	- Investment-decisions in (retro-)fitting capture module - CCTS infrastructure: Funding and de-risking	Feasibility studies, pilot projects, public invitations to tender for CO ₂ disposal, investment decisions, policy advocacy
Policy makers	- Political targets - Balance of interests	- Policy making - Agenda setting	Climate acts, Net-zero targets, motions
Federal admin.	Implementation of political targets and laws, e.g. Climate Strategy, Climate Act	- Regulation - Incentivization - Consultations - Funding	Legislative processes including consultations, Sector agreements, stakeholder engagements, Project funding
Cantonal admin.	Implementation of political targets	- Regulation (e.g., pipeline, air pollution, CO₂ storage) - Investment & funding (e.g., city-cantons)	Regulative approval procedures, project funding
Municipalities	- Implementation of sustainability targets - CO₂ storage solutions - Regulation (air pollution)	Investment if they are also operator of point source	Project funding, invitations to tender for CO ₂ disposal
Sector associations	- Planning security - Clear regulative framework - Fair conditions of competition	- Coordination of sectoral efforts and initiatives - Agenda setting - Policy advocacy	Sector agreements, Roadmaps, project, joint project funds,
Research	- Topic advocacy - Funding	- Technical and systemic innovation - Stakeholder engagement - Impact assessments and foresight	R&D, feasibility studies, LCAs, Stakeholder engagement, Science policy dialogue
Solution providers	- Business case - Regulative framework for upscaling - Long-term funding	- Innovation, demonstration of solutions - Agenda setting through tangible solutions	R&D, Offer technical solutions, feasibility studies, LCAs, business case development, Consulting, Policy advocacy
Civil society	- Sustainable solutions for hard-to-abate emissions that can scale quickly - Iterative upscaling for steep learning curve and to avoid lock-ins	- Agenda setting & policy advocacy - Add credibility to solutions (reputation) - Caution/ watch environmental and social impacts	Stakeholder engagement and platforms, public reports, public opinion formation/ debate
CCU advocates	- Investments in CCU value-chains - Policies incentivizing CCU - Integration in European hydrogen infrastructures	- Agenda setting - Policy advocacy	R&D, policy advocacy, Public relations

Table 3: Typical interests and scopes of influence by stakeholder group in Switzerland, based on interviews and informal exchange with stakeholders.

Levels of engagement: Advocates, Observers and Cautioners

Organizations and individuals differ in their level of interest and involvement in the topic of CCTS/CCUS in Switzerland. At the current early stage of discussions, we found that persons who are highly involved are generally advocating for the implementation of CCTS/CCUS. In this pioneering role, they try to find solutions and convince others *within and outside their organization* to prioritize the topic. Next to the pro-active stakeholders, most other societal actors are relatively unfamiliar with the topic and at an early stage of opinion formation. Following the speaker positions of Boettcher et al. (2023), we therefor differentiate four simplified levels to involvement with the topic:

- Advocates
- Observers
- Cautioners
- Unfamiliar

Advocates are well-informed and proactive in advocating for or against certain pathways or factors influencing the implementation. There are currently only relatively few advocates but they are well connected through bilateral exchange, stakeholder platforms and working groups, and interdisciplinary research projects. There are single organizations that take an advocate role, especially solution providers, specialized research groups and consultancies with CCTS/CCUS at the core of their work. However, in most organizations from industry, administration and civil society, CCTS/CCUS is one topic among others and it is single individuals or subdivisions who take the role of advocates both within their organization and towards external stakeholders. Individual advocates take this role either by mandate (e.g., sustainability officer) or based on their personal convictions and initiative. All advocates strongly endorsed the implementation of one or both of the two pathways. This constellation implies that there are individual advocates with more or less decision power within their organizations. They are presented with the challenge to both promote a debate and decisions on the topic internally (while still lacking certainty in many relevant questions) and at the same time coordinate and cooperate with other stakeholders, and try to influence other stakeholders and advocate for specific regulatory and financing solutions in line with their interests. We encountered advocates among challenge owners in industry and in public administration, solution providers, research, as well as civil society.

Furthermore, we found different levels of interest and activity within stakeholder groups. For example, there are some cantonal administrations that have actively engaged in discussions on CCTS/CCUS and show support for pioneer projects in their jurisdiction. Other cantonal administrations remained more observant or even cautioning, prioritizing the reduction of GHG emission reduction in their work. Advocates are key agents in the pioneering work, but broader institutional and societal support is required for a costly upscaling of especially the CCTS pathway.

Observers and cautioners are often less familiar with the topic, often lacking time to build an in-depth understanding of the complex topic, including differences between CCS and CDR and their role for net zero. Decision-makers in this position try to evaluate relevance of CCTS/CCUS for their mandates and interests. As CCTS/CCUS gets "more real", observers and cautioners can become gatekeepers of an upscaling, either by (de-)prioritizing the topic when allocating resources or by openly opposing to their implementation. Observers and cautioners who own or operate CO₂ point sources (challenge owners) are mainly concerned about investment risks and the economic viability. They tend to caution from becoming a first mover and wait to learn from pioneers before allocating any major resources to the implementation of CCTS/CCUS.

In civil society, policy making and administration, we encountered no active opposition to the two pathways, but questions regarding the priority and political will, as well as skepticism whether CCTS/CCUS is systemically the most desirable and societally accepted solution (see also sub-section on stakeholders' premises above).

While most stakeholders acknowledge the potential of the two pathways, the following cautioning arguments were expressed:

- There is a risk of competitive disadvantages for affected sectors and especially early-movers due to the high costs of the two pathways.
- There could be a lack of societal acceptance of the high costs and the distribution of costs in society.
- There could be a lack of local acceptance for storage sites and transport infrastructure and transport-related emissions (e.g., noise emissions from road transport).
- There is a risk of technological lock-in preventing other sustainable transformations over decades (e.g., in the construction, waste, biomass and energy sectors) or innovation with regard to other utilizations for captured CO₂ (CCU, e.g., CO₂-based fuels).
- There are concerns that affected sectors could use the topic to negotiate privileges with regulators and policy makers that are in contradiction to other sustainability targets.
- The uncertain promise of negative emissions in the order of megatons of CO₂ through CCTS/CCUS comes at the risk of mitigation deterrence (moral hazard).
- There are concerns regarding the carbon accounting of CCUS, as the carbonization of demolished concrete is actually only taking CO₂ back that had been emitted previously in the cement production. This concern comes with an appeal to define system boundaries for carbon accounting in a stringent and transparent manner and avoid over-selling of the climate impact of this pathway.

Based on the interviews, we identified common questions and needs:

Advocates may ask: "How can I convince my organization (and others) to invest resources in (1) exploring, (2) positioning itself, (3) investing in or implementing CCTS/CCUS?"

To answer these questions, they need:

- Support in scaling next steps in decision-making that are ambitious but feasible to promote and implement under uncertainty.
- Resources to advocate the topic within their organization, i.e., science-based narratives, facts, and key indicators (e.g., CO₂ effectiveness, energy penalty, etc.), and tangible examples and case studies.
- Access to a community of fellow advocates, experts, and experienced practitioners to share resources and best practices, develop visions and strategies together, and collaborate.

Observers and Cautioners may have questions on different levels: "How are my interests affected?", "Why should we give CCTS/CCUS and negative emissions priority and resources now?", "Is it riskier for my organization to be an early mover or to wait and observe?" But also: "Should we spend so much on climate change mitigation?", "Does the whole value chain really make sense for the climate?" and "How can society avoid a technological lock-in and systemic trade-offs?".

These uncertainties can be addressed by:

- Engaging proactively: Transparent and timely information and engagement, especially on projects and policies that get concrete, to ensure cautious voices are heard at an early stage when feedback can still be incorporated.
- Providing planning security: CCTS/CCUS pathways come with decision horizons of many years and even decades. Decision-making can be supported by reliable long-term policies and clear regulation, iterative processes, concessions, and risk transfer for long-term investments. Further, a sound theoretical basis and a hands-on proof-of-concept can support decision-making.
- Providing key performance indicators: Transparent and credible numbers on CO₂ efficiency and energy penalty of the whole value-chain of a specific CCTS/CCUS implementation, environmental impacts, as well as social and economic cost help build trust and support decision making under uncertainty.

- Leading by example: Exchange with real people, exposure to success stories, and provision of examples can make the topic more tangible and exciting.

When engaging with observers and cautioners, their concerns should be acknowledged, and a common ground found together to enable the implementation of mitigation pathways that have a strong and cross-sectoral societal support.

Stakeholders who are still unfamiliar and uninvolved with the topic were not subject of this study. However, the results and recommendations regarding the level of knowledge, attitude and communication needs of the general public can be consulted for approaching and engaging with stakeholders who are new to the topic (see Deliverable 5.6).

3.3 International Stakeholders (Q1b)

In Section 3.2, we present an overview over relevant international stakeholder groups with relevance for the faith of CO₂ captured in Switzerland.

Internationally, the landscape of stakeholders with relevance for CCTS and CCUS has grown in recent years. In the following, we briefly introduce international stakeholder groups with direct relevance for Swiss CCTS/CCUS. For each group, a list of key stakeholders is provided in Table A2 in the Annex of this report or – if available – external resources are referenced.

Solution Providers

Technologies and services for CCTS/CCUS are provided by various international companies. Next to the technical requirements, the location, connectivity, and modalities of CO₂ hubs, concrete mineralization, and geological storage sites in Europe are key parameters for the export of CO₂ from Switzerland for storage abroad. In Table A2, we list companies and consortia involved in developing and operationalizing solutions. While this is not exhaustive, it provides an overview of the types of companies that provide solutions along the CCTS pathway. According to IEA (2023a), geological storage projects in Europe have been announced in on- and offshore territory of the following countries: Denmark, France, Greece, Iceland, Italy, Netherlands, Norway and United Kingdom (see Table A2).

In DemoUpCARMA, the focus for geological storage solutions was on international sites with potential relevance for Switzerland. Potential storage sites were examined in Work Package 4, Subtask 2.3.

CDR Buyers and Marketplaces

The growing voluntary carbon market (VCM) for CDR can play a role in financing both the upscaling and the long-term upkeep of (biogenic) CCUS/CCTS activities. While in past years, the most traded CDR credits by far have been biochar-based, the diversity of CDR methods present in the VCM will likely increase in the future. According to the International Energy Agency (IEA), “only around 2 [Megatons] of biogenic CO₂ are currently captured per year, mainly in bioethanol applications. Plans for around 20 facilities together capturing around 15 [Megatons] CO₂ per year of biogenic emissions have been announced since January 2022.” (IEA, 2023b)

The following platforms currently provide comprehensive data and reports on the dynamic landscape of CDR suppliers, purchasers, and marketplaces:

- [CDR.fyi](https://www.cdr.fyi/)¹³
- [AlliedOffsets](https://alliedoffsets.com/reports/)¹⁴
- [Climate Action Tracker](https://climateactiontracker.org/)¹⁵

As a community driven effort, CDR.fyi provides public information on their methodology and a comprehensive list of data sources. The platform also tracks prices and volumes purchased and delivered per CDR method worldwide.

Financing for biogenic CCTS/CCUS through the VCM requires the commitment to deliver high-quality CDR at a certain price. Based on the stakeholder interviews, the VCM is not (yet) suited to fund nor de-risk the kind of long-term investments required for the installation and of CC units and the build-up of costly infrastructure. For the kind of investments required, several stakeholders mentioned the need for coordinated public and private investment from Swiss entities, including the challenge owners (see Section 3.1).

Policy Makers and Regulators in Europe

European policy makers and regulators are key stakeholders for the development and regulation of CO₂ management infrastructure and storage sites in Europe. This includes both the bodies of the European Union (EU), especially the European Commission, and the national governments. Clear and binding bilateral agreements between European countries are seen as a possible framework that could possible accelerate the build-up of cross-border infrastructure and CO₂ hubs. Depending on regulation and the innovative landscape in the EU, non-geological storage (CCUS) could also become more relevant and possibly accessible for Swiss CO₂. Private sector associations can play a role in setting regulatory or VCM standards, for example the CCS+ Initiative or the European Network of Transmission System Operators for Gas ENTSOG (Carbon Limits & DNV, 2021).

Associations and Civil Society in Europe

International associations and civil society organizations connect stakeholders and exert influence mainly via policy advocacy and outspoken positioning on political strategies, laws and projects, as well as opinion-forming activities, e.g., public relations and topical publications.

Based on statements and exchange with representatives from associations and civil society organizations at topical stakeholder workshops and the study by Boettcher et al. (2023), they can be roughly divided into three subgroups with differentiated positions on CDR and CCS related topics: environmental NGOs interest groups, new climate NPOs and industry and sectoral associations.

Environmental NGOs sometimes position themselves as precautionary gatekeepers seeing CCS (and CDR) as “potentially risky distractions” in climate policy. The Climate Action Network (CAN) Europe is an example organization taking this stance towards CDR, portrayed by Boettcher et al. (2023). According to this analysis, CAN Europe is not generally opposed to CDR but has communicated from the position of a precautionary gatekeeper. Recent informal exchange with stakeholders from environmental NGOs suggests a (potentially increasing) tendency to adopt the position of pragmatic integrationists instead or in parallel to cautioning. Pragmatic integrationists see CDR “as a way to compensate for unavoidable residual emissions”, acknowledging its role in long-term climate policy (Boettcher et al., 2023).

¹³ <https://www.cdr.fyi/>, last accessed 20 September 2023

¹⁴ <https://alliedoffsets.com/reports/>, last accessed 29 August 2023

¹⁵ <https://climateactiontracker.org/>, last accessed 29 August 2023

New climate NPOs with a clear focus on the mitigation of climate change have emerged in recent years, some of them with a specific focus on CDR and/or CCS and less mutual reservations against industrial stakeholders than more time-honored environmental NGOs. For example, the advocacy organization Bellona is portrayed as taking the position of a utilitarian solutionist, advocating for CDR and CCS “as an effective carbon management solution” (Boettcher et al., 2023). However, some new climate NPOs also tend to position themselves as either agenda setting innovators or responsible information providers (based on informal exchange with stakeholders).

Industry and sectoral associations of relevance can be differentiated between industrial sectors confronted with the challenges but also opportunities of decarbonization on the one hand (e.g., the gas industry) and newer associations representing the interests of the developing CDR and CCS related sectors. Associations can act as advocates and agenda setters both towards policy makers and more “inward” towards their members. In this function, they can potentially act as agents for sector-wide and cross-sectoral coordination of efforts and project.

The local civil society and other locally affected interest groups become key stakeholder when it comes to the acceptance of projects on the ground, such as infrastructure for CO₂ transport and storage, and interference with the landscape, the geological underground and other place factors. Iceland presents an interesting case, as a country with large CO₂ storage potential and already realized projects in this field. As part of the projects CDR-PoEt and DemoUpCARMA, Risk Dialogue conducted interviews with Icelandic stakeholders concerning Direct Air Carbon Capture and Storage (DACCS) and CCTS. Insights from this case study will be presented and discussed separately in the report of the DemoUpStorage Deliverable 5.1 (forthcoming), as well as a research paper (Oh et al., forthcoming).

CCTS/CCUS Pioneer Projects

Pioneer projects have successfully demonstrated the feasibility of large-volume CC from point sources. A number of projects demonstrating and operationalizing CCS and CCU pathways exist worldwide and many more have recently been announced (IEA, 2023a). However, it should be noted, that existing projects often come with links to the fossil oil and gas industry, either when it comes to the source of emissions or the storage sites (depleted gas fields, CO₂-EOR). CO₂-EOR projects exist in Brazil, Canada, China, the United Arab Emirates, and the United States, but come with a small contribution and only low relevance for net-zero (IEA, 2023a), even threatening decarbonization in the energy sector (mitigation deterrence). This limits the lessons that can be learned from these projects for the pathways demonstrated with DemoUpCARMA and discussed in the Swiss context. Pioneer projects demonstrating CC from the waste and cement sectors in Europe are potentially more interesting to watch closely and exchange experiences with. Of the two projects in Europe at waste-to-energy plants, only one is operational at the time of this report. For the cement sector, multiple industrial CC projects are announced for the late 2020s. The fastest project, scheduled for 2024, is found in Norway. Exemplary international sites demonstrating large-volume CC in the waste and cement sectors are:

- AVR Duiven in the Netherlands (waste-to-energy), CC operational since 2019¹⁶,
- Hafslund Oslo Celsio AS in Norway (waste-to-energy), CC planned¹⁷ (currently on hold),
- Breivik cement plant by Heidelberg Materials in Norway, CC planned for 2024¹⁸.

¹⁶ <https://www.avr.nl/en/optimal-process/co2-capture-plant/>, last accessed 29 August 2023

¹⁷ <https://www.celsio.no/oslo-ccs>, last accessed 29 August 2023

¹⁸ <https://www.heidelbergmaterials.com/de/co2-abscheidung-und-speicherung>, last accessed 29 August 2023

4. Recommendations for Stakeholder Engagement (Q4)

We derived a set of four recommendations for stakeholder engagement in the context of CCTS/CCUS, based on the results presented above and the experience of Risk Dialogue in stakeholder engagements around emerging technologies.

The recommendations are published in a separate commentary paper (Eberenz and Dallo et al., submitted):

- “Engaging With Relevant Stakeholder Groups”
- “Differentiating Advocates, Observers, Cautioners, and the Unfamiliar”
- “Differentiating the Systemic Challenge and Specific implementations”
- “Adapting Engagement Strategies Over Time”

5. Conclusion

There are currently multiple stakeholders in Switzerland across sectors actively advocating for and working on solutions for CCTS/CCUS in Switzerland. Other affected stakeholder groups should be engaged with early on in implementation projects and regulatory processes. The storage of CO₂ in demolished concrete is already operational and ready to be scaled up. The main strength of the CCUS pathway demonstrated in DemoUpCARMA is perceived by stakeholders in its proven integration in existing value-chains and its flexibility, making it a fitting decentralized solution for small CO₂ point sources such as biogas plants. Cross-border CCTS is perceived as more suited for large-point sources such as cement and waste-to-energy plants. However, the CCTS pathway has yet to move beyond prove of concept.

Across stakeholder groups, we further differentiate three positionings towards CCTS/CCUS of individuals and organizations: advocates, observers and cautioners. Advocates see no alternative to CCTS/CCUS for reaching the Swiss climate goals. Observers and cautioners want to see proof that CCTS/CCUS makes sense both for climate mitigation, as well as from an economic perspective. Besides the stakeholders active in the topic, many stakeholders with (future) relevance are not yet very familiar with the topic.

We found that there is a relatively small group of highly engaged stakeholders across sectors with a shared general understanding of the role and requirements of CCTS/CCUS pathways in Swiss climate policy and action. The stakeholders active in the topic agree that upscaling of CCTS/CCUS requires regulatory clarity and the development of financing/business cases, as well as a coordinated approach towards the various parts of the value chains from capture to storage of CO₂, to resolve chicken-and-egg problems regarding interdependent investment decisions. However, priorities, particular interests, and agency diverge between stakeholders.

Developments in CCTS could potentially be hindered by lack of planning security, unclear responsibilities and mandates, and trigger conflicts in interest and delays. Especially the “chicken-and-egg problem” with regards to investments and long-term financing of capture, transport and geological storage of CO₂ is seen as a major blockade by many stakeholders. To overcome this, coordinated efforts between the private and public sectors are needed and many pro-active stakeholders are currently very engaged in stakeholder processes to create momentum in the topic.

In this dynamic setting, policy makers, regulators and implementers should acknowledge that it is currently mainly experts and advocates of CCTS/CCUS who are involved in these discussions. Once the implementation of large-scale and costly CCTS starts “getting real”, more previously unaffected stakeholders need to get involved. A broader and societal engagement, also with potentially more cautioning positions will be required. At a systemic level, the role of CCTS/CCUS in climate policy and sustainable transformations should be debated in a transparent and open manner. For the

implementation on the ground, local residents and interest groups should be involved in a transparent and participatory manner. It should be noted that normative aspects as well as the relationships between stakeholders were not the focus of this study. These two issues should receive further attention in the future, especially when it comes to the fair financing and local implementation of CCTS and CCUS pathways.

This study and the recommendations will support the further progress in the topic and help institutions and individuals involved in CCTS/CCUS to engage with all relevant stakeholders in a meaningful manner.

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8. Annex

A1. List of Stakeholders in Switzerland

Primary Stakeholder Group	Organisation
Associations	CemSuisse
	Swiss Society of Engineers and Architects (SIA)
	scienceindustries
	swisscleantech
	Swissmem
	Swisspower AG
	Verband der Betreiber Schweizerischer Abfallverwertungsanlagen VBSA
	Verband Schweizerischer Elektrizitätsunternehmen VSE
	Verband der Schweizerischen Gasindustrie VSG
CCU advocates	Avenergy Suisse
	Swiss Airlines
	Synhelion
CCUS product users	Agir
	Eberhard
	Spross Recyclingbeton
	Public procurers
Challenge Owners	Emitters / CO ₂ Point Sources
	Policy makers and regulators
	Sectoral associations of emitters
Civil Society	Alliance Sud
	Clima Now
	Greenpeace Schweiz
	Klimaallianz
	Schweizerische Energiestiftung
	Stiftung ZAR
	Stiftung Risiko-Dialog
	Swiss residents (Public)
	Verein Klimaschutz Schweiz
Emitters / CO₂ Point Sources - Cement plants, - Waste-to-energy plants, - Waste water treatment plants, - Biogas plants, - Wood-fired power plants, - Chemical and other industry.	WWF Schweiz
	ARA Region Bern AG (waste-water treatment)
	ARA Werdhölzli, ERZ (waste-water treatment)
	Arxada (chemistry)
	AXPO (energy)
	Ciments Vigier SA / Péry (cement)
	Energie Auszerschwyz AG (energy)
	Holcim (Schweiz) / Eclépens, Siggenthal, Untervaz (cement)
	Jura-Cement-Fabriken AG: Wildegg (cement)
	Juracime SA: Cornaux
	Kalkfabrik Netstal AG KFN (clinker)
	KVA GEVAG (waste-to-energy)
	KVA Horgen (waste-to-energy)
	KVA Linth (waste-to-energy)
	Lonza AG (chemistry)
	Regionalwerke Baden: biogas plant Nesselbach (energy)
	Swisspower AG (energy)
Investors and CDR buyers	AXA
	Carbonremoval Partners
	KLiK
	UBS
	Zurich Re

Locally affected & Public	<i>Locally and specifically affected interest groups and residents</i>
	<i>Swiss Public</i>
Policy makers and regulators / Political parties	<i>Politicians and party secretariats</i>
	BAFU/FOEN
	BFE/SFOE
	<i>Cantonal administrations, e.g. BS, AG</i>
	<i>Cantonal governments</i>
	Cercle Climat (Cantonal Conference KVV)
	City of Zurich
	Federal Council (Bundesrat)
	Canton/City BS
	Swiss association of towns and cities (Städteverband)
	Swisstopo
	<i>Municipalities, e.g. Zurich, Basel</i>
	<i>Municipal waste, energy and heat clusters (Verbünde)</i>
Research	EAWAG
	EMPA
	EPFL Lausanne
	ETH Zurich
	HS Luzern
	OST Rapperswil
	PSI
	Università della Svizzera Italiana
	University of Geneva
	ZHAW
Solution providers	Airfix
	Cargo Sous Terrain
	ChemOil Logistics AG
	CO ₂ -Kompetenzzentrum (KVA Linth)
	EnUmtec
	Erdgas Ostschweiz
	GETEC Park
	Hitachi Zosen Inova HZI
	Infras
	Kästli Bau AG
	National Rhine Navigation Authority
	Neustark AG
	Salzmann AG Transporte
	SBB Cargo
	Sika Technologies AG
	Sulzer Chemtech
	Swiss Association for Shipping & Port Management (SVS)
	Swiss Rhine Ports (SRH)
	UniSieve
	VARO Energy Holding AG
	zirkulit AG

Table A1: List of selected stakeholders in Switzerland with relevance for CCTS/CCUS sorted by their primary stakeholder groups. Stakeholder types are written in italic. In some groups, only exemplary stakeholders who are active in and/or outspoken about CCTS/CCUS or CDR are listed. This list is without claim to completeness.

A2. International Stakeholders with Potential Relevance for Swiss CCTS

Stakeholder	Primary Stakeholder Group	Additional Information
Carbon Business Council	Associations	Industry association
CCS+ Initiative	Associations	Thinktank
Concawe	Associations	Industry association
Deutscher Verband für negative Emissionen e.V. (DVNE)	Associations	Industry association
European Network of Transmission System Operators for Gas (ENTSOG)	Associations	Regulators
Gas Infrastructure Europe (GIE)	Associations	Industry association
Global CCS Institute	Associations	Thinktank
International Association of Oil & Gas Producers (IOGP Europe)	Associations	Oil and gas companies
Negative Emissions Platform	Associations	Industry association
Rethinking Removals	Associations	NGO
Bellona Europe	Civil Society	NGO
CAN International	Civil Society	NGO
Carbon Gap	Civil Society	NGO
Children's Investment Fund	Civil Society	NGO
Clean Air Task Force	Civil Society	NGO
Climateworks Foundation	Civil Society	NGO
European Climate Foundation	Civil Society	NGO
Public and civil Society in storage countries	Civil Society	
Holcim	Emitters (Point-Sources)	Cement
European Commission	Regulators & Policy Makers	Government
Governments in storage countries	Regulators & Policy Makers	Government
InnoTech Alberta	Research	CCS pioneer project
Perspectives Climate Research	Research	Consultants
Technology Centre Mongstad	Research	Consultants and Service Providers
Acorn CCS (United Kingdom)	Solution Providers	CO ₂ Storage
Aker	Solution Providers	CCS Technology
Altera Stella Maris CCS / Havstjerne (Norway)	Solution Providers	CO ₂ Storage
Aramis (Netherlands)	Solution Providers	CO ₂ Storage
Associated British Ports	Solution Providers	CO ₂ Transport & Distribution
AVR Duiven	Solution Providers	CCS pioneer project
Bacton Thames Net Zero initiative / Hewett gas field (United Kingdom)	Solution Providers	CO ₂ Storage
Bifrost (Denmark)	Solution Providers	CO ₂ Storage
BP	Solution Providers	Oil and gas companies
Carbfix / Coda Terminal (Iceland)	Solution Providers	CO ₂ Storage
Carbon Limits	Solution Providers	Consultants
Carbon Management Canada	Solution Providers	CCS Technology
Delta Cleantech Inc	Solution Providers	CCS Technology
Eemshaven port terminal (Netherlands)	Solution Providers	CO ₂ Transport & Distribution

Eni	Solution Providers	Oil and gas companies
Entropy Inc	Solution Providers	CCS Technology
Equinor	Solution Providers	Oil and gas companies
Errai (Norway)	Solution Providers	CO ₂ Storage
EU2NSEA (Norway)	Solution Providers	CO ₂ Storage
EVERGAS	Solution Providers	CO ₂ Transport & Distribution
Exxon	Solution Providers	Oil and gas companies
Fluxys / fluxswiss	Solution Providers	CO ₂ Transport & Distribution
Fortum	Solution Providers	CDR provider
Greensand (Denmark)	Solution Providers	CO ₂ Storage
Hafslund Oslo Celsio AS	Solution Providers	CCS pioneer project
Interconnector	Solution Providers	CO ₂ Transport & Distribution
L10 CCS (Netherlands)	Solution Providers	CO ₂ Storage
Liverpool Bay CO2 storage (United Kingdom)	Solution Providers	CO ₂ Storage
Low Carbon Solutions (Exxon Mobile)	Solution Providers	Oil and gas companies
Medway CCS Hub (United Kingdom)	Solution Providers	CO ₂ Storage
Mitsubishi Heavy Industries, Ltd.	Solution Providers	CCS Technology
Nationalgrid	Solution Providers	CO ₂ Transport & Distribution
Neptune Energy L10 Area CCS (Netherlands)	Solution Providers	CO ₂ Storage
Northern Endurance Partnership (United Kingdom)	Solution Providers	CO ₂ Storage
Northern Lights / Aurora (Norway)	Solution Providers	CO ₂ Storage
NSMP	Solution Providers	CO ₂ Transport & Distribution
OGE/TES	Solution Providers	CO ₂ Transport & Distribution
Oxy Low Carbon Ventures Carbon Finance Labs	Solution Providers	Oil and gas companies
PanGas / Linde Engineering	Solution Providers	CCS Technology
Peel NRE	Solution Providers	CO ₂ Transport & Distribution
Polaris (Norway)	Solution Providers	CO ₂ Storage
Porthos (Netherlands)	Solution Providers	CO ₂ Storage
Prinos (Greece)	Solution Providers	CO ₂ Storage
Puro.earth	Solution Providers	Consultants and Service Providers
PYCASSO hub (France)	Solution Providers	CO ₂ Storage
Ravenna Hub / Callisto (Italy)	Solution Providers	CO ₂ Storage
Shell Quest	Solution Providers	Oil and gas companies
Smeaheia (Norway)	Solution Providers	CO ₂ Storage
SNAM	Solution Providers	CO ₂ Transport & Distribution
Southpole	Solution Providers	Consultants and Service Providers
Spirit Energy CCUS hub (United Kingdom)	Solution Providers	CO ₂ Storage
Svante	Solution Providers	CCS Technology
TotalEnergies	Solution Providers	Oil and gas companies
Trelleborg and Fyrkat (Denmark)	Solution Providers	CO ₂ Storage

Trudvang (Norway)	Solution Providers	CO ₂ Storage
Viking CCS Phase 1 (United Kingdom)	Solution Providers	CO ₂ Storage
VTG	Solution Providers	CO ₂ Transport & Distribution
Wintershall Dea / Luna (Norway)	Solution Providers	CO ₂ Transport / Storage
Wolf Midstream	Solution Providers	CCS pioneer project

Table A2: Stakeholder List International with potential relevance for CCTS with CO₂ from Switzerland. This list is without claim to completeness.

A3. Interviewees by Stakeholder Group

Stakeholder Group	Number of Interviewees
Associations (Industry)	2
Challenge Owners	5
Industry (Emitters)	2
Public administration / Regulators	3
Civil Society (NGOs)	2
Investors and CDR buyers	2
Politicians	1
Solution Providers	5

Table A3: Number of interviewees per stakeholder group (Total = 17). Further stakeholders were engaged with during workshops and informal exchange.

A4. Interview Questions

1. What are your function / responsibilities in your organization?
2. How would you describe your level of knowledge regarding the two pathways demonstrated within DemoUpCARMA?
What relevance do they have to your work?
3. *[Optional: Brief input on the procedures along infographic (Figure 1) and clarification of questions of understanding.]*
4. Do you have an (official) mandate or ongoing project related to CCUS/CCTS?
Please elaborate.
5. What is your interest and attitude towards the CCTS/CCUS pathways and a possible implementation in industrial scales?
6. Could your organization influence future developments/implementations in the field?
How?
7. What possible future developments could influence your interest/activities in the field?
8. Is there anything else related to the topic that you would like to talk about?
9. What kind of information and results would you find useful for your work to get from DemoUpCARMA?
10. How would you like to get informed and possibly engaged with regard to future CCTS/CCUS projects?
11. Who else should we talk to (inside and outside your organization/sector)?

Table A4: Guiding questions for semi-structured interviews.

A5. Questionnaire

General

- G1.** How would you assess your level of knowledge regarding CCUS and CCTS? **R, E, S**
- G2.** Where do you see yourself in terms of CCUS and CCTS at the moment, and what is your prospect for the future (planned projects, allocated resources/budgets, foreseen partnerships)? **R, E, S**
- G3.** What role does CCUS or CCTS play in current or future climate (or other) policy targets – _and if that role is not quantitatively specified, what process will lead to target specification? **R, E**
- G4.** In your view, what benefits could result from this project for the future of CCUS/CCTS? **R, E, S**
- G5.** Do you have any concerns regarding the scale-up of CCUS/CCTS in Switzerland? What kind of challenges do you see/expect? **R, E, S**
- G6.** How relevant is CCTS/CCUS for you in comparison to other decarbonization activities, i.e. where are the priorities, how are limited resources allocated, and what would be necessary to shift priorities more towards CCTS/CCUS? **R, E, S**

Financial

- F1.** Where do you see the biggest financial challenges regarding CCUS/CCTS in the future? **R, E, S**
- F2.** Are there financial incentives which could tackle these financial challenges? **R, E, S**
- F3.** Do you see a long-term role for the government subsidizing CCUS/CCTS? If not, how do you envisage these activities will achieve viable business cases? **R, E, S**
- F4.** Are you planning to invest in CCUS/CCTS technologies in the near, medium or long-term future? If yes, when, which technologies and where would you raise the funds to finance it? What fundraising challenges do you foresee? **E**
- F5.** What role do you expect governments to play for maintaining viable business cases for CCUS/CCTS based mitigation in the long term? **E, S**
- F6.** For a large-scale CCUS/CCTS deployment, a CO₂ transport network will most likely be necessary in Switzerland. In your opinion, who and how should finance and operate it? **R, E, S**
- F7.** Do you expect current (market) instruments to be sufficient for meaningful business cases in the short, medium and long-term? **S**

Regulatory

- R1.** Which regulatory hurdles have to be overcome for the success of CCUS/CCTS? **R, E, S**
- R2.** What support do you need (e.g. from experts, industries, or interest groups) to address regulatory hurdles (create a mandate to change problematic regulations)? **R**
- R3.** In the mid to long term, do you see the need for the CCUS/CCTS industry to be strongly regulated (e.g. with an independent federal regulator) or rather weakly regulated? Why? **R**
- R4.** Which regulatory approach do you think is most suitable in the medium to long term (e.g. a command-and-control approach or a market-based approach, or a combination thereof)? **R, E, S**

R5. Which are the main constraints and/or opportunities for CCUS/CCTS regulations in Switzerland based on the existing international regulatory framework (e.g. EU rules, EU-CH ETS linking agreement, Paris Agreement)? ^R

R6. Do you have the necessary capacity to comply with the regulatory environments for a) the respective activities themselves and b) tapping into carbon-based revenue streams? ^E

R7. Do you feel uncertain about future regulatory hurdles, and if so, is this a barrier for further development and adoption of CCUS/CCTS? ^{E, S}

Technical

T1. What technical challenges are preventing the next steps in adoption of (particular types of) CCUS/CCTS? ^{E, S}

T2. What specific form of CC(U)S do you see ready for market, what other forms do you anticipate might only get there several years later? ^E

T3. What is the pathway to technology readiness for non-ready technologies? ^E

Acceptance

A1. What processes of public engagement are currently planned? ^R

A2. How do you intend to build-up long-term public mandates in line with the envisaged role of CCUS/CCTS under long-term climate targets? ^R

A3. In your view, which current and future developments and trends could influence the public debate regarding CCUS/CCTS in the next years and decades? In which way? ^{R, E, S}

A4. What kind of concerns and demands from external stakeholders and the public would you expect for a scale-up of CCUS/CCTS in Switzerland and Europe, including the built up of considerable infrastructures and e.g. transport of CO₂? If possible, specify the stakeholders and the rationale behind potential concerns? ^{R, E}

A5. How do you intend to prevent likely public backlash against costly CCUS/CCTS, NIMBY-rejection (Not in my backyard) or other rejection of CCUS/CCTS-supporting policies or CCUS/CCTS infrastructure? ^R

A6. How can our activities be aligned to enable constructive public engagement? ^R

A7. Do you anticipate significant acceptance challenges – locally to infrastructures or nationally to the very idea of CCUS/CCTS or to public policies supporting CCUS/CCTS? ^{E, S}

A8. What is your strategy to avoid public rejection and strengthen public support for CCUS/CCTS? ^{E, S}

Organizational

O1. Are there other stakeholders which could be involved in this project? Which could be beneficial in achieving a long-term upscaling in CCUS/CCTS? ^R

O2. How do you intend to ensure that progress on CCUS/CCTS is made across industries and fairly – to ensure build-up of a portfolio of novel mitigation options while also ensuring efficiency; what role can our project play therein? ^R

O3. Which groups, organizations and stakeholders should be approached, informed, heard, or involved in the demonstration and scale-up of CCUS/CCTS? ^{E, S}

Communication

C1. Do you communicate information about CCUS/CCTS to stakeholders of society (e.g., public)? If yes, to whom and with which strategy/approach? If not, why not? ^{R, E, S}

C2. In your experience, what are common misunderstandings/misbeliefs when communicating information about CCUS/CCTS to stakeholders of society? **R, E, S**

C3. Which challenges do you face or expect when communicating information about CCUS/CCTS to stakeholders of society? **R, E, S**

Open

Open 1. Did we miss any issues/questions that you think we should address or CCUS/CCTS topics that you would be interested in? **R, E, S**

Table A5: Questions of questionnaire sent out to consortia members, as well as FOEN and SFOE, in 2022. Not all questions were posed to all members. The letters "R", "E", and "S" demarcate which group each question was posed to: Regulators (R), Emitters (E), and Service Providers (S). The joint questionnaire was compiled and sent out by working package 5 of DemoUpCARMA, namely by researchers from ETH Zurich, Perspectives Climate Research, south pole, Università della Svizzera Italiana and the Risk Dialogue Foundation.

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Deliverable D5.6: Report on the current knowledge and public perception of the Swiss public towards CCTS and CCUS

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Contents

Abbreviations	3
Abstract	4
Zusammenfassung	4
1 Introduction	5
2 Background	6
2.1 Technical and political background	6
2.2 The societal perspective	7
2.2.1 Knowledge	7
2.2.2 Perceived risks and benefits	8
2.2.3 Perception and acceptance of CCTS/CCUS	9
2.2.3.1 Positive drivers	10
2.2.3.2 Negative drivers	10
2.3 Research gaps and questions	10
3 Methods	11
4 Results	13
4.1 Focus groups	13
4.1.1 Ice breaker: Useful technical innovation	13
4.1.2 Description of the two pathways	14
4.1.3 Open questions to experts	14
4.1.4 Perceived risks and benefits	16
4.1.5 Take-home messages	19
4.1.6 Conclusions	19
4.2 Public survey	20
4.2.1 Sample characteristics and personal factors (independent variables)	20
4.2.2 General CCTS/CCUS knowledge and support	21
4.2.3 Specific CCTS/CCUS pathways	21
4.2.3.1 First impression	21
4.2.3.2 Specific familiarity	23
4.2.3.3 Comprehension	23
4.2.3.4 Specific acceptance (index)	23
4.2.3.5 Specific support	24
4.2.3.6 Perceived risks	25
4.2.3.7 Perceived benefits	26
4.2.3.8 Design perception	26
4.2.3.9 Further questions	27
4.2.3.10 Local storage acceptance [only Icelandic pathways; n=262]	28
4.2.4 Evaluation of the transportation means	28
4.2.5 Evaluation of the origin of CO ₂	30
4.2.6 Communication preferences	30
5 Discussion	31
5.1 Public perception, acceptance and support of CCTS/CCUS	31
5.1.1 Positive drivers of acceptance and support	31
5.1.2 Negative drivers of acceptance and support	31
5.1.3 Benefits, risks and preferred transportation means	32
5.2 User-centred communication	33
6 Conclusion and outlook	33
7 Acknowledgment	33
8 References	34
9 Annex	37

Abbreviations

CC	Carbon Capture
CCS	Carbon Capture and Storage
CCTS	Carbon Capture, Transportation and Storage
CCU	Carbon Capture and Utilization
CCUS	Carbon Capture, Utilization and Storage
DemoUpCARMA	Demonstration and Upscaling of CARbon dioxide MAnagement solutions for a net-zero Switzerland
CDR	Carbon Dioxide Removal
DACCS	Direct Air Carbon Capture and Storage
FOEN	Federal Office for the Environment
GHG	Greenhouse gas emissions
IPCC	Intergovernmental Panel on Climate Change
M	Mean
NET	Negative Emission Technologies
NIMBY	Not In My Backyard
SD	Standard Deviation
SED	Swiss Seismological Service
SFOE	Swiss Federal Office of Energy
Q&A	Questions and Answers

Abstract

To achieve the Swiss climate goals by 2050, carbon capture transportation/utilization and storage (CCTS/CCUS) is indispensable to reduce the hard-to-abate emissions. DemoUpCARMA is a pilot project that evaluates the feasibility and potential of two pathways and their upscaling: (i) CO₂ utilization and permanent storage in recycled concrete in Switzerland, and (ii) CO₂ transport and permanent storage in geological reservoirs in Iceland. In addition to the technological, economic and regulatory factors, a further focus was set on the societal perspective. Regarding the latter, the two primary aims were (i) to assess the Swiss public perception of, familiarity with, acceptance of, and support for the two pathways envisioned in DemoUpCARMA, and (ii) to evaluate different communication products to provide recommendations on how to best inform the public about CCTS/CCUS. To this end, we conducted six focus groups in July and August, 2022, and an online survey in June, 2023. As part of the online survey, we did a between-subjects experiment to test different communication products which presented the same information about CCTS/CCUS. Our results, among others, indicate that (i) Swiss people are not familiar with the two pathways and CCTS/CCUS in general; (ii) acceptance and support is driven by various personal factors (e.g., people's climate change concerns); (iii) perceived benefits and risks depend on the CO₂ capture, transport, and storage processes; and (iv) infographics are preferred over written text. Our findings and the recommendations derived from them are intended to help institutions and agencies responsible for communicating with the public to adequately inform them about CCTS/CCUS projects, taking into account people's attitudes, concerns, and preferences.

Zusammenfassung

Die CO₂-Abscheidung, -Transport, -Nutzung und -Speicherung (CCTS/CCUS) ist unabdingbar, um die "schwer vermeidbaren" Emissionen zu reduzieren und somit die Schweizer Klimaziele bis 2050 zu erreichen. DemoUpCARMA ist ein Pilotprojekt, das die Machbarkeit und das Potenzial von zwei CCTS/CCUS Pfaden und deren Hochskalierung evaluiert: (i) CO₂-Nutzung und dauerhafte Speicherung in Abbruchbeton in der Schweiz und (ii) CO₂-Transport und dauerhafte Speicherung in geologischen Reservoirs in Island. Neben den technologischen, wirtschaftlichen und regulatorischen Faktoren stand auch die soziale Perspektive im Fokus des Projekts. Diese Studie hatte daher zum Hauptziele (i) die Wahrnehmung, das Wissen, die Akzeptanz und die Unterstützung der Schweizer Bevölkerung hinsichtlich der beiden CCTS/CCUS Pfade des DemoUpCARMA Projekts zu erheben und (ii) verschiedene Informationsprodukte zu testen, um Empfehlungen für die Kommunikation zu CCTS/CCUS mit der Öffentlichkeit abzuleiten. Zu diesem Zweck haben wir im Juli und August 2022 sechs Fokusgruppen und im Juni 2023 eine Online-Umfrage durchgeführt. Im Rahmen der Online-Umfrage haben wir ein «between-subjects» Experiment durchgeführt, um verschiedene Kommunikationsprodukte mit dem gleichen Informationsinhalt zu CCTS/CCUS zu testen. Unsere Ergebnisse zeigen unter anderem, dass (i) die Schweizer Bevölkerung mit den beiden Pfaden und CCTS/CCUS im Allgemeinen nicht vertraut ist; (ii) die Akzeptanz und Unterstützung von verschiedenen persönlichen Faktoren abhängt (z. B. je grösser die Besorgnis der Leute über den Klimawandel, desto grösser ihre Akzeptanz und Unterstützung); (iii) die wahrgenommenen Vorteile und Risiken abhängig sind von den angewandten Prozessen zur CO₂-Abscheidung, -Transport und -Speicherung; und (iv) Infografiken gegenüber rein schriftlichem Text bevorzugt werden. Unsere Ergebnisse und die daraus abgeleiteten Empfehlungen sollen Institutionen und Behörden unterstützen, die breite Öffentlichkeit angemessen über CCTS/CCUS-Projekte zu informieren und dabei die Einstellungen, Bedenken und Präferenzen der Leute zu berücksichtigen.

1 Introduction

All pathways to limit global warming to 2°C above pre-industrial levels and to achieve 'net zero emissions'¹ require rapid decarbonization (IPCC, 2022). Since the society will not be able to entirely eliminate carbon emissions cost-effectively (e.g., hard-to-abate sectors such as aviation and agriculture) and must remove legacy emissions, CO₂ reduction and removal from the atmosphere is needed too (Ho, 2023). Thus, to achieve the climate goals by 2050 and limit global warming to 2°C, Carbon Dioxide Removal (CDR) efforts (also known as Negative Emission Technologies (NETs)) must be fostered including Carbon Capture, Transportation, Utilization and Storage (CCTS/CCUS) (Honegger, 2019; IPCC, 2022). CCTS/CCUS can be implemented at point sources with fossil (cement, chemical plants) or biogenic (biogas plants) emissions. In the first case, CO₂ is reduced and, in the second case, CO₂ is removed (i.e., CDR). The current planning of the countries to implement CCTS/CCUS are rather low compared to the amount of CO₂ that should be captured (Smith et al., 2023). Thus, more investigations are needed, in particular for the upscaling.

There are various (research) efforts around the world to evaluate the potential of CCTS/CCUS technologies. Among these projects is the pilot project DemoUpCARMA (Demonstration and Upscaling of CARbon dioxide Management solutions for a net-zero Switzerland) led by ETH Zurich. It aims to demonstrate the implementation and scale-up of two specific pathways leading to negative emissions (Figure 1):

- 1) CO₂ utilization and permanent storage in recycled concrete in Switzerland using a novel technology.
- 2) CO₂ transport and permanent storage in a geological reservoir in Iceland.

The interdisciplinary research teams of DemoUpCARMA assess the optimal design of these pathways and their upscaling potential considering technological, economic, regulatory, political, and societal factors. The project is funded and supported by the Swiss Federal Office of Energy (SFOE) and the Federal Office for the Environment (FOEN), as well as ETH Zurich. This report specifically focuses on the societal factors and provides insights about the current familiarity, support, acceptance, and perception of the Swiss public towards CCTS/CCUS. Further, we provide an overview of public support drivers, including socio-demographic as well as personal factors (e.g., technological affinity), and recommendations for the design of user-centered communication products.

To this end, we conducted six focus groups and an online survey with the Swiss public. The focus groups allowed us to assess public knowledge gaps about, perception of, and acceptance of CCTS/CCUS. Based on the insights from the focus groups, we then designed different communication products and analysed their influence on people's support, acceptance, correct comprehension of the information provided, and perception of the two CCTS/CCUS pathways. This allowed us to derive recommendations for the design of effective communication products that can be used by institutions responsible for public communication to inform the public about CCTS/CCUS while addressing their concerns and knowledge gaps.

The novelty of our study is that public support and perception on two concrete CCTS/CCUS pathways has not been assessed before; prior studies have focused on CCTS/CCUS in general without explaining the capture, transportation, and storage processes (Jobin & Siegrist, 2020; Wenger et al., 2021). Further, we for the first time evaluated the influence of different communication products (i.e. infographics, written text, LinkedIn posts, and Q&As) on people's perception and support. This allowed us to derive recommendations for information campaigns to inform the public about the technologies in an understandable, clear, and well-perceived manner.

¹The greenhouse gas (GHG) emissions which are produced are also removed from the atmosphere; leading to a net balance of zero GHG emissions.

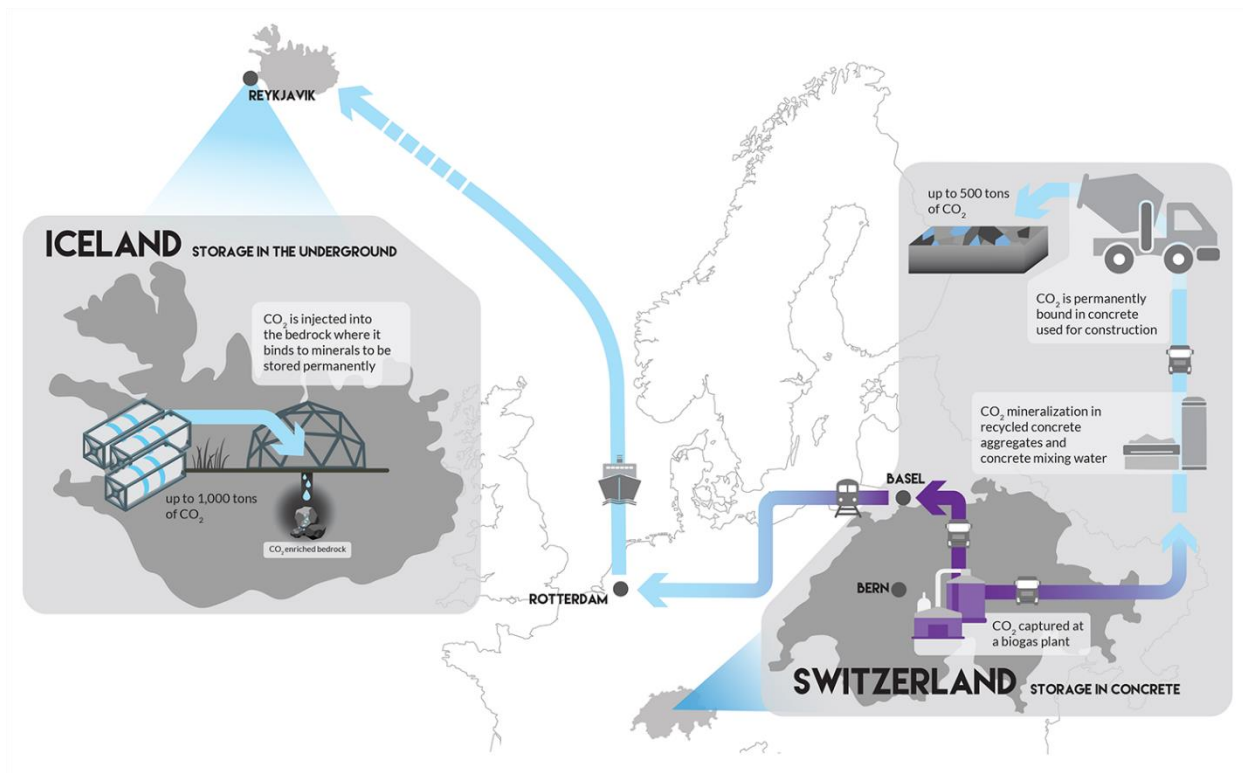


Figure 1: Infographic of the two pathways to reduce CO₂ emissions envisioned by DemoUpCARMA

In addition to public communication, it is also important to effectively engage relevant stakeholders in research projects and CCTS/CCUS implementation and operations. As part of DemoUpCARMA, a research group specifically addressed this issue and made recommendations in its report *D5.5 – Map of relevant stakeholders (with preferences/ concerns) and recommendations for further action in the field of communication and social acceptance towards CCTS/CCUS*.

2 Background

2.1 Technical and political background

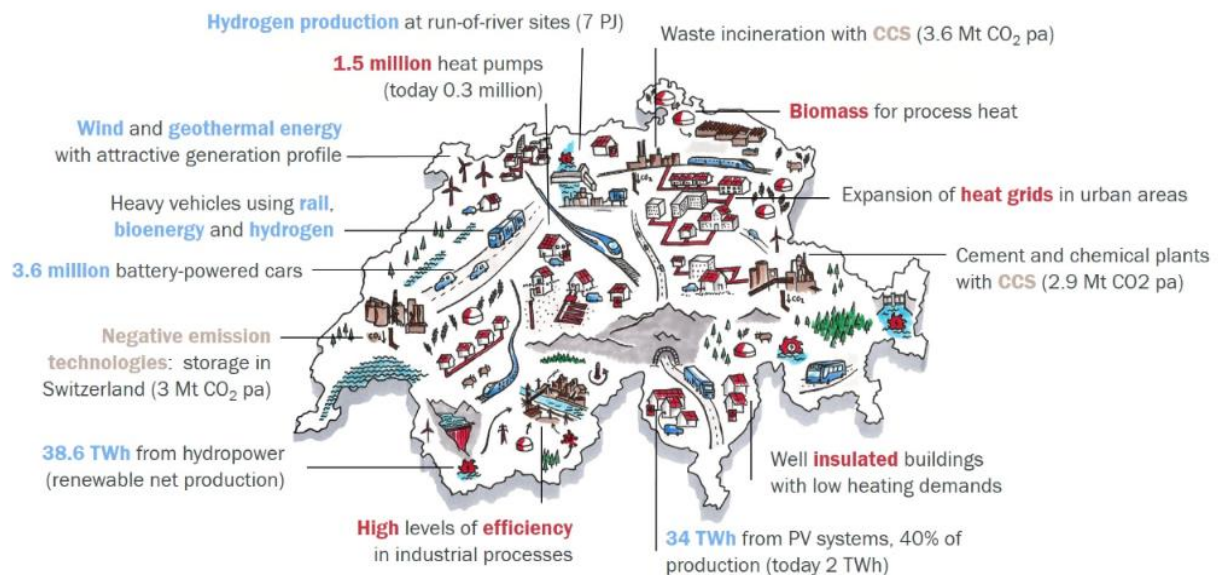
In recent decades, greenhouse gas emissions (GHG) from human activities have increased, leading to a rise in global average temperature and, consequently, to severe consequences for natural and human systems (IPCC, 2022). To minimize these impacts, GHG emissions must be drastically reduced until 2050, primarily by decarbonization (IPCC, 2018). In addition, the Intergovernmental Panel on Climate Change (IPCC) report shows that the pathways leading to net zero emissions by mid-century also rely on the use of CCS and CDR efforts (Honegger, 2019; IPCC, 2018).

Carbon Capture (CC) is a process to capture CO₂ before it enters the atmosphere and to either use it (CCU) or to store it typically in geological formations (CCS). CC always includes CO₂ separation, compression, transport, and storage/utilization (Nick & Thalmann, 2021). In general, there are three techniques to separate CO₂ from flue gases, namely post-combustion, pre-combustion, and oxyfuel combustion. The CO₂ can then be transported by pipeline, ship, rail, or truck to be either processed or stored underground (Nick & Thalmann, 2021). Utilizations of CO₂ are for example food additives (Valluri et al., 2022), mineral carbonation (Valluri et al., 2022), enhanced oil recovery (Nick & Thalmann, 2021), or CO₂-cased fuels (Simons et al., 2021).

In comparison, CDR efforts remove CO₂ from the atmosphere and can be classified in biological, chemical, and artificial processes. Examples of specific processes are afforestation, bioenergy with carbon capture and storage (BECCS), or direct air capture and storage (DACCS) (Nick & Thalmann,

2021). Some of them are already widely used such as afforestation (Bellamy, 2020) and others are not yet deployed at a large scale such as DACCS.

Regarding our case country, Switzerland aims to be climate neutral by 2050. The Swiss Federal Council stated in its report that since the Paris climate goals and the Swiss climate goals for 2050 can no longer be met by emission reductions only, the expansion of CDR (NETs) and CCS efforts is needed (FOEN, 2020). These goals are part of the Swiss Energy Strategy 2050, with which Switzerland should be able to maintain the high energy supply standard and to reduce the energy related emissions. In order to achieve these goals, and thus to comply with the Paris Climate Agreement, various measures were defined (Figure 2). Two of these measures are fundamental: i) reduction of the energy consumption and CO₂ emissions and ii) compensation for the residual emissions through CCS and CDR.



Graphics: Dina Tschumi; Prognos AG

Figure 2: Objectives for a climate-neutral Switzerland by 2050, retrieved from
<https://www.bfe.admin.ch/bfe/en/home/policy/energy-perspectives-2050-plus.html/>

2.2 The societal perspective

Besides the technological, economic, and regulatory assessments, the societal issues must be addressed too for various reasons. First, the adoption of CCTS/CCUS technologies depends on multiple factors such as national frameworks and policies, which must be co-created by all relevant stakeholders. Second, public acceptance is critical because, as we have seen with other technologies such as geothermal power plants, public opposition can hinder projects (Stauffacher et al., 2015). Thus, involving the public from the beginning is key to monitor the ongoing discourses in the society. Third, in some countries, the public will vote on whether or not a project should be implemented and therefore needs understandable and clear information to make scientifically sound decisions. In sections 2.2.1 to 2.2.4, we thus summarized the research addressing the societal issues related to CCTS/CCUS.

2.2.1 Knowledge

A study in 2008 showed that the public is not familiar with CCTS/CCUS and their knowledge about CCTS/CCUS is limited (Wallquist et al., 2009); which has not changed in the last decade (Wenger et al., 2021). This conclusion is in line with other studies showing limited knowledge about CCTS/CCUS in Spain (Oltra et al., 2010), in the UK (Perdan et al., 2017; Shackley et al., 2004), in Switzerland (Jobin & Siegrist, 2020; Wenger et al., 2021), and in China (Li et al., 2017). Given that, people are particularly sensitive to framing; the ways actors communicate information about CCTS/CCUS to the public (Bellamy & Raimi, 2023). "However, low levels of awareness and

comprehension of CCU also mean that there is a considerable potential for public perception to be shaped by relevant stakeholders” (Perdan et al., 2017, p. 75).

2.2.2 Perceived risks and benefits

Various studies have assessed which risks and benefits people link with CCTS/CCUS and which concerns they have. We provide an overview of these perceived risks in Table 1 and the benefits in Table 2. Overall, further research is needed to assess which risks are accepted by the public and which not and which benefits outweigh the risks. These insights allow one to address people’s concerns in communication products.

Table 1: Overview of the perceived risks by the general public

Perceived risks	Sources
Environmental risks	
- Negative impacts on the ecosystem/environment (e.g., pollution)	- (Arning et al., 2019; Li et al., 2017; Oltra et al., 2010; Wallquist, 2011)
- Altering nature	- (Oltra et al., 2010)
- Groundwater pollution	- (Li, Liu, Cai, et al., 2017; Wallquist, 2011)
- Impact on marine environment	- (Li et al., 2017)
- Induced earthquakes	- (Wallquist, 2011)
- Soil acidification	- (Wallquist, 2011)
- Rapid release of a big amount of CO ₂ (effect on global climate)	- (Li et al., 2017)
- High energy use to capture, compress and transport CO ₂ at large scale and build infrastructure	- (Li et al., 2017; Nick & Thalmann, 2021)
- Neglection of environmental justice	- (von Rothkirch & Ejderyan, 2021)
Social risks	
- Impact on human health	- (Arning et al., 2019; Oltra et al., 2010)
- Health risk of workers at the storage site	- (Li et al., 2017)
- Opposition of local population (to import foreign CO ₂)	- (Merk et al., 2022; Oltra et al., 2010)
- Opposition of local environment NGOs	- (Oltra et al., 2010)
- Fear of waste dump to poor countries	- (Oltra et al., 2010)
- Storage similar perceived as radioactive waste storage	- (Nick & Thalmann, 2021)
- Dependency on other countries (e.g., transportation through other countries)	- (Li et al., 2017)
- NIMBY (Not in My Backyard) phenomenon	
Economic risk	
- Incentive to further use fossil fuels	- (Oltra et al., 2010; Satterfield et al., 2023)
- High investment costs	- (Nick & Thalmann, 2021; Oltra et al., 2010)
- High costs for building, maintaining and retrofitting pipelines	- (Nick & Thalmann, 2021)

Technological risk	
- Leakage releases (due to e.g. failures, accidents, undetected faults)	- (Oltra et al., 2010; Satterfield et al., 2023; Wallquist, 2011)
- Unproven technology	- (Oltra et al., 2010)
- Explosions during transportation/storage processes	- (Oltra et al., 2010)
- Capacity limits to store CO ₂	- (Oltra et al., 2010)
- Limited efficacy of technologies	- (Oltra et al., 2010)
- Transportation pipelines impact on environment, ground landscape	- (Li et al., 2017)
Others	
- Not solving the problem of emissions	- (Oltra et al., 2010)
- CCTS/CCUS only removes CO ₂ and no other pollutants such as PM _{2.5} , sulphur dioxide, benzene, ozone, nitrogen oxides, carbon monoxide	- (Nick & Thalmann, 2021)
- Reduction of awareness of the CO ₂ emission problems	- (Oltra et al., 2010)
- Uncertainties and unknown impacts in the future	- (Oltra et al., 2010; Wallquist, 2011)
- Perceived uncontrollability	- (Arning et al., 2020)

Table 2: Overview of the perceived benefits by the general public

Perceived benefits	Sources
Environmental benefits	
- Reduction of CO ₂ emissions	- (Oltra et al., 2010)
- Effective in combating climate change/ impacts of global warming	- (Li et al., 2017; Perdan et al., 2017)
- Improvement of air quality at location	- (Perdan et al., 2017)
- Reduction of water pollution at location	- (Perdan et al., 2017)
- Addressing climate severity and urgency	- (Satterfield et al., 2023)
Social benefits	
- Part of a broader strategy to reduce CO ₂ emissions and mitigate climate change	- (Oltra et al., 2010)
Economic benefits	
- Reuse of CO ₂	- (Oltra et al., 2010)
- Exploitation of carbon reservoirs	- (Oltra et al., 2010)
- Benefits for local communities (e.g., jobs)	- (Oltra et al., 2010; Perdan et al., 2017)
- Reduced electricity price or transport fuel price	- (Perdan et al., 2017)
Technological benefits	
- Bridging technology while renewable energies are deployed	- (Oltra et al., 2010)
- Achievement of current energy demand	- (Oltra et al., 2010)

2.2.3 Perception and acceptance of CCTS/CCUS

Several studies have shown that people's acceptance towards CCTS/CCUS varies with respect to the technology used; with a moderate acceptance on average (Wenger et al., 2021). Thereby, studies have mainly focused on public's perception and acceptance with respect to CCTS/CCUS in general or specifically the storage technology and not the capture and transportation processes

(Tcvetkov et al., 2019). However especially “CO₂ capture” and “CO₂ transport” are highly acceptance-relevant life cycle steps (Offermann-van Heek et al., 2020). Only Wallquist et al. (2012) looked at it in more detail and suggest that options *without* pipelines are preferred over options *with* a (CO₂) pipeline. In comparison, in another study about hydrogen transportation it was showed that the public prefers transportation via pipelines over trucks (Hämmerli, 2019).

2.2.3.1 Positive drivers

Technologies that are perceived as “natural”, such as afforestation, rank highest in public acceptance (Jobin & Siegrist, 2020; Wenger et al., 2021). Thus, linking CCTS/CCUS to natural processes can increase positive reactions towards these technologies (Oltra et al., 2012). Moreover, perceived benefits increase general CCTS/CCUS acceptance (Arning et al., 2020; Simons et al., 2021) or support (Jobin & Siegrist, 2020). Merk et al. (2022) have also shown that Norwegians have a higher acceptance of CCTS/CCUS when the CO₂ is domestically sourced and not foreign, which challenges the current plans of Northern European states to store their CO₂ in Norway (Merk et al., 2022). In comparison, for German people there is no difference whether the CO₂ is captured in another country or Germany itself (Merk et al., 2022). von Rothkirch and Ejderyan (2021) further concluded that local factors (e.g., environmental concerns, population density, environmental justice) can increase public acceptance.

Additionally, the framing of the technologies is key. Indicating that it is part of an overall strategy or measure portfolio increases people’s support (Oltra et al., 2010). Also, the frame “technological fix” was well perceived, thus that the impacts of climate change can be minimized by technological efforts (Wenger et al., 2021). However, different societal groups prefer different framings (Whitmarsh et al., 2019), which challenges any communication campaign.

Further, a higher level of trust in industry, science, and government increases the level of public support (Jobin & Siegrist, 2020). In China, for example, the most trusted sources are academic journals and textbooks, television, radio and newspapers, expert lectures, and brochures (Li et al., 2017). Further, acceptance rates are significantly higher when people receive adequate technical background information (Offermann-van Heek et al., 2020) and information which addresses their concerns (Dechezleprêtre et al., 2022). In line with this, Offermann-van Heek et al. (2020) showed that whenever more detailed information is given and, consequently, people have the chance to make informed decisions, acceptance is higher.

2.2.3.2 Negative drivers

There are also various factors that decrease public acceptance. Especially in the context of CO₂-technologies, the sceptical and ambivalent public attitude towards infrastructure is largely based on health and environmental concerns (Arning et al., 2019). Moreover, perceived uncontrollability (Arning et al., 2020), preferences for other climate mitigation measures such as energy efficiency efforts or the upscaling of renewable energy (Oltra et al., 2010), perceived risks and tampering with nature (Jobin & Siegrist, 2020) decrease public acceptance. Further, when the government is perceived as having a special (own) interest, support can be inhibited (Oltra et al., 2010). Also mentioning the costs of deploying CCTS/CCUS can lead to lower support, thus costs should be discussed in the context of the broader energy system transformation so that people have a comparable basis (Whitmarsh et al., 2019). Moreover, the investigations in Iceland (storage underground in basalt) showed that the public also has concerns about ocean acidification, land protection issues, and the high water consumption (Grettisson, 2023). They are thus asking for a proper environmental assessment (Grettisson, 2023).

2.3 Research gaps and questions

Based on our literature review we identified four main research gaps. First, prior research has provided relevant insights on how the public generally perceives CCTS/CCUS technologies and which risks and benefits are publicly discussed. What is missing is the assessment of whether people (would) accept certain risks because the benefits outweigh them. Second, several studies have shown that people know little or nothing about CCTS/CCUS, but research is missing about what they would actually like to know or which information they would need to decide whether to

support a technology or not. Third, the acceptance has mostly been assessed for CCTS/CCUS in general. Studies that look at specific pathways that are tangible and concrete are missing. Fourth, studies recommend to provide technical background information about the technologies or information addressing public concerns, but best practices and guidelines are missing on how to design these communications so that people with different backgrounds understand them correctly. We thus addressed the following two overarching research questions with regards to the CCTS/CCUS pathways envisioned in DemoUpCARMA:

- 1) *What is the Swiss public's familiarity, support, perceived risks and benefits, and acceptance of the two CCTS/CCUS pathways envisioned in DemoUpCARMA?*
- 2) *How can understandable communication be designed to adequately inform the public about CCTS/CCUS, taking into account their preferences and needs?*

3 Methods

We applied a transdisciplinary approach, by collaborating with scientists from different disciplines and involving the general public (Pohl et al., 2021). This allowed us to take into account latest research findings gained in the project DemoUpCARMA, address the research questions from different scientific perspectives, and consider public perspectives. To involve the public, we conducted in-person focus groups (qualitative method) and an online survey (quantitative method), which allowed us to understand people's thinking in depth and to derive evidence-based recommendations for the design of suitable communications (see Figure 3). The focus groups were conducted in July and August 2022, and the online survey from June 1st to June 7th, 2023. The participants of the online survey were recruited through the ISO-accredited polling company Bilendi. Both studies were approved by the Ethics Committee of ETH Zurich (EK 2022-N-105).

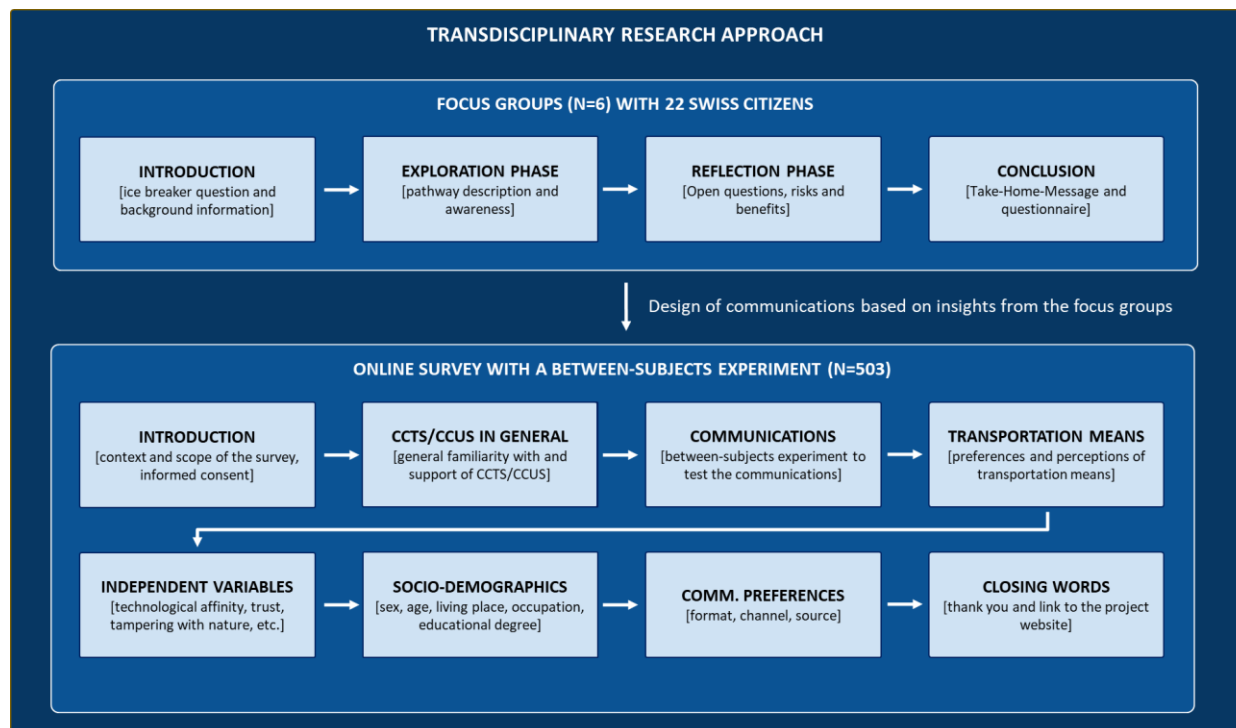


Figure 3: Overview of the research procedure: focus groups (qualitative method) and survey (quantitative method).

First, we conducted six focus groups (n=22) with the aim to assess public's knowledge (gaps), knowledge interests, perceived risks and benefits, and general acceptance (Oltra et al., 2010). The focus groups lasted on average one hour and were conducted in-person at different places near participants' living or working places. Thus, participants were in a known and pleasant environment. Further, the participants received the information sheet beforehand via email and signed the consent form on site. The discussions were moderated by one person and one person took notes. The procedure of the discussions consisted of four parts (Annex A-1):

- 1) *Introduction round*: Participants introduced themselves [ice breaker: what was a technological innovation that positively influenced your life?]
- 2) *Exploration phase*: The moderator first introduced the frame (i.e. Swiss energy strategy 2050), emphasizing that the two CCTS/CCUS pathways are part of a measure mix and do not substitute the other measures (e.g. expansion of renewable energies). Second, participants were shown the infographic with the two pathways (Figure 1) and were asked to describe them in their own words. This allowed us to identify misconceptions. Third, we asked them whether they had already heard about these pathways and, if yes, where.
- 3) *Reflection phase*: Participants had five minutes to note down on post-its any risks and benefits they link with the two pathways and all questions they would like to ask experts. Afterwards, they jointly discussed and evaluated which risks are acceptable and which benefits are especially essential.
- 4) *Conclusion*: As a last step, participants were asked to state one take-home message from the discussion and to fill in a brief questionnaire assessing their sex, age, highest educational degree, occupancy, climate change awareness, and technology affinity.

Second, we designed four versions of communication products for both pathways – storage in basalt in Iceland and storage in concrete in Switzerland – based on the insights of the focus groups (see Annex B-1): an infographic, a Q&A, a LinkedIn post, and a written text. The information on the communication products was reviewed by experts from different disciplines to make sure that the latest research findings from the projects were taken into account. These communications were then tested with a between-subjects experiment in an online survey, which means that participants were randomly assigned to one version of the communication product but had to answer the same questions. The survey consisted of six questions blocks (QB), whereby we derived the items from the focus groups to get representative data on issues raised in the discussions (e.g., perceived risks and benefits; Nassar-McMillan & Borders, 2002) and prior studies (see below). The entire survey is listed in Annex B-2 and here we provide a brief summary of it:

- 1) *Introduction & Consent*: Participants received a description of the scope and context of the survey and had to give consent to participate.
- 2) *QB1 – CCTS/CCUS in general*: First, we briefly explained what Switzerland defined in its climate strategy regarding the reduction of CO₂ emissions and that to this end CCTS/CCUS are needed. Second, we asked participants if they know what CCTS/CCUS is and if they support it (adapted from Wenger et al., 2021).
- 3) *QB2 – The communications*: In this block, we conducted the between-subjects experiment, where participants were randomly assigned to one of the eight versions of the communications (see Table 3). After a brief explanation of the pathway, participants had to indicate their first impression. Afterwards, we assessed participants' knowledge about, acceptance of (Arning et al., 2020), support of (Jobin & Siegrist, 2020), and perceived risk and benefits related to the two pathways (focus groups and (Oltra et al., 2010; Li et al., 2017; Arning et al., 2020; Nick and Thalmann, 2021)). Further, we evaluated participants' correct comprehension of the provided information, perception of the design of the communications, and missing information. Further, we assessed if people would also support the geological underground storage in Switzerland (Arning et al., 2020).

Table 3: Overview of the testing arms of the public survey

Version	Pathway	Communication product	n	%
1	Icelandic pathway	Infographic	75	14.9
2	Icelandic pathway	Q&A	72	14.3
3	Icelandic pathway	LinkedIn post	62	12.3
4	Icelandic pathway	Written text	53	10.5
5	Swiss pathway	Infographic	58	11.5
6	Swiss pathway	Q&A	62	12.3
7	Swiss pathway	LinkedIn post	52	10.3
8	Swiss pathway	Written text	69	13.7

- 4) *QB3 – Transportation means*: Further, we let participants rate if they perceive the different transportation means (train, ship, pipeline, and truck) as secure, environmental-friendly, cheap, efficient, suitable for the transportation in Switzerland, and politically implementable. Further, we asked them which mean they would in general support.
- 5) *QB4 – Independent variables*: Here, we assessed if the origin of the CO₂ plays a role whether participants support CO₂ storage in Switzerland or not (Merk et al., 2022). Further, we assessed some personal factors which may have an influence on participants' support and perception of the CCTS/CCUS pathways: climate change concern (Jobin & Siegrist, 2020), technological affinity (Ohlsen, 2018), trust in the involved stakeholders (Wenger et al., 2021), and political orientation (Gerber et al., 2010).
- 6) *QB5 – Communication preferences*: We further asked participants in which format, via which channel, and from whom they would like to receive information about such pathways/technologies in the future.
- 7) *QB6 – Socio-demographics*: Here, we assessed participants' gender, age, living place, highest educational degree, and occupation.
- 8) *Closing words*: On the last page, we thanked the participants for taking the time to fill in the survey and provided a link to the DemoUpCARMA project website in case they were interested in further information.

4 Results

Chapter 4 is divided into two parts, in which we summarize the results of the focus groups (section 4.1) and the online survey (section 4.2). The outputs of the focus groups are listed in Annex A-2.

4.1 Focus groups

In total, we conducted six focus groups of 3-5 participants (n=22). 36.4% of the participants were female and 63.3% male, and the mean age was 47.4 (SD = 20.9). Half of the participants had a university degree (n=11) and the other half either completed an advanced technical college (n=4), a Matura (n=4), or a technical college (n=3). Further, most of them were full-time employed (n=9) or part-time employed (n=4), 4 participants were in education without remuneration, and 5 participants were retired. We further assessed participants' climate change awareness and technology affinity, by using the scales from (GESIS, 2022; Ohlsen, 2018). On average, participants had a high climate change awareness (M = 1.7, SD = 1.5), except one person who believed that there is no anthropogenic-induced climate change. Additionally, the participants had a moderate technological affinity (M = 3.8, SD = 1.0), whereas they were especially not sure whether the development of a technology should continue when it poses unknown risks (M = 2.5, SD = 1.1).

In sections 4.1.1 to 4.1.6, we list the results of the focus groups along the procedure of the discussions: ice breaker, description of the pathways, open questions to experts, perceived risks and benefits, and take-home messages. For the number of focus groups, a large capital "N" is used and to indicate the number of participants who mentioned it, a small capital "n" is used.

4.1.1 Ice breaker: Useful technical innovation

As an icebreaker question, we asked participants to introduce themselves and indicate one technology which positively influenced their lives. Most mentioned smartphones (n=7), computers (n=5), electric bike (n=2), and the internet being an information access for everyone (n=3). Also stated but only by individuals were: maps (n=1), Facebook to stay connected (n=1), electricity (n=1), Dyson air cleaner helping against allergies (n=1), car to be more mobile (n=1), the function on the laptop to make virtual notes (n=1), combine harvester (n=1), bicycle (n=1), transistors (n=1), and solar energy technologies (n=1). The reasons why they chose these innovations were that these technologies/functions are either most used in the daily lives or facilitate certain actions.

4.1.2 Description of the two pathways

As a first step, participants had to describe the two pathways they saw on the infographic (Figure 1). In general, they described the steps of the two pathways correctly. However, some difficulties and misconceptions were present, which are summarized in Table 4.

Table 4: Overview of participants' misconceptions about the infographic

Pathway 1: Storage in concrete in Switzerland	Pathway 2: Storage in geological reservoir in Iceland
- Mineralization means grinding ("abschleifen") - When concrete is mixed, CO₂ is released - CO₂ is captured from the air	- CO₂ from the sea is stored underground (not CO₂ from Switzerland) - CO₂ is solved and, in turn, stored in the sea water - Not clear how the CO₂ is stored underground, as a liquid or does it become stone - CO₂ is dumped on the seabed - Iceland is the only country where it can be stored - Transportation process goes under in the visual
Both pathways It was not clear for many participants that the starting point for both pathways is at the bottom right in Switzerland (i.e. biogas plant): - Some had the impression that the path starts at the top right and ends at the top left. - Some thought that they are independent pathways, one in Iceland and one in Switzerland (grey boxes); connection with the biogas plant not realized.	

We also asked participants if they had heard of these pathways before, and if so, where. In general, most participants had at least heard of one of them; however not in detail. Most heard of it in the media, read newspaper articles, or learned about it in their studies at university. Further the pathways were compared to other technologies known to them, namely the process of accessing crude oil, the project in Dotternhausen in Germany where oil shale is mined and recycled in a CO₂ neutral way, CO₂ storage in Norway, and the DACCS effort in Hinwil in Switzerland. Since the participants of the focus groups were quite different, we here summarize the insights per focus group:

- In the first focus group, the participants were students who mentioned that they have already heard about the process done in Iceland in their lectures. In comparison, the concrete option was not known that well, only one participant mentioned that he heard of a start-up called "neustark" which is doing it.
- In the second focus group, the participants were architects and they had all heard of the concrete process at Swissbau or in a lecture during their Masters. Further, one participant knew KIBAG and heard about a start-up doing it too and, in turn, looked for information in the internet. The Icelandic pathway, in comparison, was only known by one participant who heard about it in the media.
- In the third focus group, only one participant had already heard about the Icelandic pathway but not in detail. Further, three of them heard about the concrete CO₂ storage process in the media or in the context of the vote for the energy strategy 2050. None of them had detailed knowledge about the pathways.
- In the fourth focus group, one participant heard about the Icelandic pathway from a neighbour who also works on a similar project. The other participants learnt about it from an interview with Dr Bastien Girod (green party politician in the Swiss parliament). The concrete pathway in Switzerland they knew from work and the media.
- In the fifth group, one participant has not heard of the pathways but the other three heard of it in the media (e.g. newspaper, television). Two participants even heard that KIBAG is already doing it.
- In the sixth focus group, one participant read the magazine "Die Umwelt" where these technologies were described. Another participant heard of the geological reservoir storage but not the specific one in Iceland. And the third participant saw a TV report on the CO₂ storage in concrete.

4.1.3 Open questions to experts

In Table 5, we list all the questions participants would like to ask to experts. It is visible at first glance that the participants have a lot of questions, thus they are curious to learn more about the

two pathways and CCTS/CCUS in general. Further, the questions address all stages of the pathway: capture, transportation and storage/utilization.

Table 5: Overview of the open questions participants would like to ask to experts regarding the two pathways separately and both together. In brackets, we indicate in how many focus groups the issues were mentioned.

Pathway 1: Storage in concrete in Switzerland	Pathway 2: Storage in geological reservoir in Iceland
- How much CO₂ rests in the concrete and for how long (i.e. lifespan of concrete, demolition process)? (N=4) - Functional differences between normal concrete and CO₂-concrete (e.g., loss of quality)? (N=4) - It may be possible and more reasonable to store the CO₂ in other materials than concrete? (N=3) - Is additional energy needed to produce the CO₂-concrete, compared to normal concrete? (N=2) - How high is the purchasers' interest to buy CO₂-concrete compared to normal concrete; might be more expensive? Do they know about this offer? (N=2) - Lobbying at ETH when we focus on the concrete-industry? (N=2) - How much of the other materials can be saved by adding CO₂ to the concrete-mix? (N=1)	- Why exactly Iceland? (N=3) - What is public's acceptance in Iceland? (N=2) - How well analysed are the long-term effects (e.g. risk of earthquakes, volcanic eruptions)? (N=2) - Does the process increase the chance of earthquakes or volcanic eruptions? And what is the linked risk of CO₂ leakage? (N=2) - What happens chemically underground? Are there any "dangerous" by-products? (N=1) - Is it publicly or privately organized in Iceland? (N=1) - How long can the basalt bed/layer exist when also other countries store CO₂ there? (N=1) - Why not transport the CO₂ from countries that are nearer to Iceland than Switzerland? (N=1) - Could the CO₂ not also be stored in empty oil and gas reservoirs? (N=1)
Both pathways	
Entire process - What are the costs for both processes (more effective to invest in other technologies)? (N=6) - How efficient are the processes (i.e. energy balance, CO₂ balance)? (N=5) - How does the processes actually work in detail; e.g. what is "Mischwasser" (mixing water) or what is "CO₂ solved in sea water"? (N=4) - Are these two processes already applied/used? (N=3) - Are there similar (research) projects also in other countries, e.g. Norway? (N=3) - Where does the needed energy to implement these technologies come from? (N=3) - Are the CO₂ capture technologies only used for the sectors that cannot avoid emissions via other ways; to make sure that the other sectors still try to reduce/avoid oil and petrol? (N=2) - How high is the risk of CO₂ leakage due to for example an accident (also compared to radioactive waste); CO₂ is aggressive and could cause severe damages? (N=2) - Where different scenarios calculated, i.e. combination with other technologies? (N=2) - Can these technologies really contribute to a high extent to achieving the net-zero target? (N=2) - Are not other alternatives better, such as using CO₂ in greenhouses or other technologies? (N=2) - Can only CO₂ be captured and stored or also methane which is more severe than CO₂? (N=2) - Was the general assumption that CO₂ has to be reduced and that climate change is a problem been critically reflected? (N=1) - Are these "non-avoidable" CO₂ emissions really non-avoidable? (N=1)	
Capture process - How exactly is the CO₂ captured at the biogas plant? (N=1) - Is CO₂ also captured at other plants than the biogas plant? (N=1)	
Transportation process - Is the transportation CO₂-neutral for both processes? (N=3) - How is the transportation regulated? (N=1)	
Storage - What is the total storage capacity? (N=6)	

-
- Could not the entire CO₂ be stored in Switzerland (e.g. geological reservoirs)? (N=2)
 - Is the storage secure; can the CO₂ not escape? (N=2)
-

4.1.4 Perceived risks and benefits

In Table 6, we listed the perceived risks for the two pathways. For the risks that were discussed in more detail, we summarized participants' discussions about whether these risks are acceptable or not. Several participants stressed that each technology is risky but we must try to minimize the risks as much as we can. Further, the second focus group concluded that these pathways are less risky than other technologies such as nuclear energy for example. However, participants of all focus groups wanted to have a proper risk assessment to make sure that no other problems are triggered (e.g., drinking water contamination), before being able to decide which risks are acceptable. Further, three participants mentioned that the storage in concrete might be less risky because it is more small-scale and can always be stopped if something happens. One participant also mentioned that, if unforeseeable negative feedbacks occur, mechanisms to stop the activities should be in place. Some participants were more sceptical because for them the risks outweighed the benefits and they believed that the actual problems (reduction and mitigation) are not addressed. However, some also thought that we just need to do it to be able to minimize the (negative) impacts of climate change.

Table 6: Overview of the perceived risks

Risks	
Pathway 1: Storage in concrete in Switzerland	Pathway 2: Storage geological reservoir in Iceland
Social risks - Construction industry has no incentive anymore to get greener and reduce their CO₂ footprint. (N=2) - o <i>Concrete lobbying is supported.</i>	Social risks - Ethical/moral issues: Switzerland is exporting its problems. (N=3) - o <i>Therefore, further pathway with concrete is needed.</i> - o <i>When the other countries offer solutions, one should take them.</i> - o <i>It feels strange that the final repository is abroad. Similar to the radioactive waste problematic. However, Finland for example offers to take the radioactive waste and the local people accept it.</i> - o <i>One must ask the people in Iceland whether they agree to take the CO₂.</i> - o <i>Bad feeling when it is pumped so deep into the ground in another country.</i> - Geopolitical dependencies. (N=2) - o <i>Important to have alternatives, i.e. several places where it could be stored.</i> - o <i>One should start immediately with the cross-border agreements.</i> - o <i>What do we do when a country does not want that the CO₂ is transported through its country?</i>
Economic risks - Concrete will be more often used, and sustainable substitutes will be neglected. (N=4) - o <i>Concrete will always be used in the future, because not for all constructions good alternatives are available nowadays.</i> - o <i>Concrete is losing its bad reputation and is suddenly seen as a sustainable material.</i> - o <i>Concrete production needs a lot of energy, thus it should rather be reduced and substitutes should be found.</i>	
Technological risks - What happens after 10 years with the concrete. (N=3) - Storage capacity is only low/limited. (N=2)	Economic risks - Centralisation in Iceland; rather have several storage sites. (N=1)

Environmental risks

- Drinking water contamination. (N=2)
- Negative impacts on the underground environment (e.g. bacteria could die, loss of biodiversity). (N=2)
- CO₂ comes back to the surface due to technical problems or natural processes (e.g. volcanic eruption). (N=2)
- Volcanic eruptions might be triggered by the activities. (N=1)
 - o *Continuously monitor the seismicity and volcanic activities.*
- Environmental pollution due to ship transport. (N=1)
 - o *The oil will be substituted by hydrogen.*
 - o *Maybe there are sustainable solutions for the transport to Iceland (e.g. electric vehicles).*

Technological risks

- Leakages during transportation. (N=2)
-

Both pathways

Social risks

- No incentive to emit less CO₂; sufficiency is neglected and the needed decarbonization is slowed down. (N=5)
 - o *It is important in the communication campaign to make clear that these efforts are only for the CO₂ emissions that are not avoidable. Thus, they do not replace other measures as for example to reduce energy.*
 - o *We will not be able to go the sufficiency pathway. Thus, we need these pathways.*
 - o *Very high risk, but we have to take it because we need everything we have (especially for the unavoidable CO₂ emissions).*
 - o *Good regulation needed.*
 - o *It should not be communicated about it too much.*
- CO₂ will not be stored for ever in this way, thus future generations must again deal with it. (N=2)
- Political lobbying because people may accept it (i.e. they do not have to change their lifestyle). (N=1)
- Inertia of the political system (everything always takes so long) and, thus, we will not make it until 2050. (N=1)

Economic risks

- Financial resources wrongly invested; would be needed to improve efficiency of technologies and expansion of renewable energies. (N=2)
- High costs, whereby there may be more cost-efficient options. (N=2)
 - o *Other technologies (e.g. solar panels) were also expensive at the beginning but now not anymore.*

Environmental risks

- Health and environmental risks. (N=2)
- Other waste products at the biogas plant that may harm the environment. (N=1)

Technological risks

- Limited capacities to store enough CO₂. (N=4)
 - o *Calculate the storage capacity precisely to make correct calculations of how much CO₂ can be stored.*
 - Transportation in liquid form and under high pressure → Risk of explosions or other consequences? (N=3)
 - o *In comparison to other substances that are transported, risk is rather low.*
-

-
- *Good monitoring needed.*
 - *Must be analysed and evaluated in detail.*
 - Risk of leakage along the transportation chain (N=3)
 - High energy consumption (N=3)
 - *CO₂-balance of the entire process has to be zero or negative at the end.*
 - *Define where the energy comes from (not CO₂-intense energy sources).*
 - *Iceland could use the geothermal energy they produce.*
 - Numbers (i.e. 1000 tons of CO₂) are quite low compared to what we need to reduce. (N=2)
 - Many resources needed to build the infrastructure (transportation and plant itself). (N=2)
 - Only useable for point-CO₂ sources (e.g. KVA) and not diffuse CO₂ sources (e.g. cars). (N=1)
-

In Table 7, we list all the benefits that were mentioned. In the discussion about which benefits are especially relevant, most groups mentioned that the unavoidable CO₂ emissions can be captured and stored, which is needed to reach the net-zero goals. Further, two focus groups concluded that the combination of all the benefits is key and it is good to have both pathways together. However, research is key to assess and evaluate the benefits and risks properly. One participant stated that for him the “intervention in nature” is very important, thus he would support more the storage in concrete because the storage pathway in Iceland interferes more with nature and the impacts are not clear.

Table 7: Overview of the perceived benefits

Benefits	
Pathway 1: Storage in concrete in Switzerland	Pathway 2: Storage geological reservoir in Iceland
Social benefits - Trigger to increase society’s awareness. (N=1) - Solution also for other countries. (N=1) - Local project. (N=1)	Technological benefits - More CO₂ might be possible to store compared to the concrete process. (N=2) - Basalt storage sites are available. (N=2) - Geothermal energy can be used for the process. (N=1)
Environmental benefits - No major interventions in nature. (N=1)	
Technological benefits - Reusability of the storage mass. (N=3) - Short transportation ways. (N=3) - Opportunity to build more sustainably, i.e. climate-neutral building material. (N=2) - Safer than transporting CO₂ to Iceland. (N=2)	
Both pathways	
Social benefits - New jobs and workplaces. (N=1) - Industry helps in the fight against climate change (not only know-how but also financial resources). (N=1) - Politically easier to get acceptance because people do not have to reduce their CO₂ footprints. (N=1)	
Environmental benefits - Reduction of CO₂ emissions. (N=3) - Unavoidable CO₂ emissions can be captured and stored. (N=2)	

-
- Contributes to the chance to reach the net-zero goals. (N=2)

Economic benefits

- Incentive for biogas plants. (N=1)

Technological benefits

- Long-term storage (and not short-term). (N=1)
 - Less energy needed than for other pathways. (N=1)
-

4.1.5 Take-home messages

As a last task, participants were asked to name one key take-home message:

- Nice to see two tangible pathways on how to achieve the goals. The energy strategy is often very abstract and not comprehensible. (n=3)
- Many open questions which must be answered by the responsible institutions (addressing also the risks), before being able to say whether they would support it or not. (n=3)
- Further research is needed to do a life cycle assessment and to investigate on the risks and benefits related to both pathways. (n=3)
- Not clear how these pathways contribute in an optimal way to the net-zero goals, making sure they do not negatively impact the decarbonisation process. (n=2)
- Generally, I am critical towards these technologies. But I liked the perspective of the other participants, that these technologies let hope that we still can reach the goals. Thus, the technologies should be a motivation trigger for people to contribute to the mitigation measures.
- Nice to see that there are also pathways in Switzerland.
- Pathway with the CO₂ storage in concrete was new for me.
- Possibility of long-term storage by mineralizing the CO₂.
- We are architects and could use it in our projects.
- I would support it and will inform others about these possibilities.
- Nice to see that there are two options, storage inland and abroad.
- The older generation might be more sceptical, we are young and more open towards it.
- Exciting technologies but "fighting the causes" (Ursachenbekämpfung) is more relevant and should be invested in.
- At the end, these technologies might be important but others currently have a higher priority.
- Difficult to say what I took away from the discussion. I need to sleep another night.
- I am fascinated by the two "creative" pathways - neglecting the risks and benefits - and would like to know more about it.
- Basic assumption that CO₂ needs to be reduced must be questioned.
- Local solutions should be favoured but the standards (i.e. PC300) of concrete should be critically reflected.

4.1.6 Conclusions

From all these results, we concluded:

- The **main concept** of the two pathways on the infographic is mostly clear but the details are not understood (e.g. mineralization). One of the main issues was that it was **not clear** on the infographic that **both pathways start from the biogas plant** in Switzerland.
- Most participants **had heard at least from one of the two pathways** either in the media (TV and newspaper) or at work or school; however not in detail.
- Participants had **many open questions** they would like to ask to experts, which reflects their interest in the topic. For both pathways, they were especially interested in the **costs**, the **energy and CO₂ balance** (Bilanz), the total **storage capacity** and the CO₂-neutrality of the transportation. For the storage in concrete, they wanted to know what happens after the lifespan of the concrete, whether there are **functional differences** (between the normal and CO₂ concrete), and whether the CO₂ could not also be **stored in other materials**. For the storage in the geological reservoir, they wanted to know **why exactly Iceland**, whether the

Icelandic **people accept it** and what effects **natural hazards** could have on the process (e.g., CO₂ leakage due to volcanic eruption).

- Regarding the **risks** for both pathways, participants mentioned that these pathways **reduce the incentive to emit less CO₂** and, thus, sufficiency and decarbonization efforts are slowed down. Further mentioned risks are **limited storage capacities**, the risk of **leakage**, a high **energy consumption**, and high **costs**. For the concrete option, it was further criticized that more **sustainable substitutes will be neglected** and the **concrete lobby** can promote its products. For the storage in Iceland, participants have **ethical/moral issues** because Switzerland would export its problem to another country, and **geological dependencies** might be an obstacle.
- The main **benefit** of both pathways is that **non-avoidable CO₂ emissions can be offset** too, which allows to reach the net-zero target until 2050. Comparing the two pathways, the storage in concrete in Switzerland has **shorter transportation ways** and is a local solution (independent of other countries). The storage in Iceland on the other hand may have a **higher storage capacity**.
- Three take-home messages were mentioned several times: i) nice to see **tangible pathways** because the energy strategy is very abstract and complex; ii) **more information needed** to decide whether to support it or not; and iii) **life cycle assessment needed**, considering also the risks and benefits.

4.2 Public survey

We conducted an online survey with a between-subjects experiment, which mean that each participant is exposed to only one treatment, in Switzerland from June 1st to 7th, 2023. The survey was programmed in Unipark and pre-tested in order to improve the clarity of the questions and the technical functionalities. The participants were recruited through the ISO-accredited polling company Bilendi. We used quota sampling with quotas based on age and gender representing the population of Switzerland. In total, 679 people were recruited with an answer rate of 81%. Due to short answer durations, we had to exclude 44 participants [67].

4.2.1 Sample characteristics and personal factors (independent variables)

The final 503 participants ranged in age from 18 to 86 years ($M = 48.9$, $SD = 17.1$). 49.9% were female, 49.53% male, and three participants ticked 'divers'. Most participants worked full-time (43.5%) or part time (20.9%), and 22.9% were retired. Most of them have as the highest educational degree completed an apprenticeship (40.2%), followed by a technical college (15.7%) or an university of applied sciences (13.7%). Further, the majority lives in the canton of Zurich (25.4%), Bern (18.5%), or Aargau (11.3%). The detailed socio-demographics are listed in the Annex B-3.

We assessed four personal factors, namely people's climate change concern, technological affinity, trust in various stakeholders, and political orientation (see Annex B-4). Aggregated over all participants, they had high levels for climate change concern ($M=4.0$, $SD= 1.0$) and medium levels for technological affinity ($M=3.5$, $SD=0.9$). Regarding their political orientation, the mean lied in the middle ($M=3.0$; $SD=0.9$). Further, participants trusted most scientific research institutions, followed by public companies, non-governmental organizations, and governmental and authoritative agencies (Figure 4). Least trusted are industrial companies.

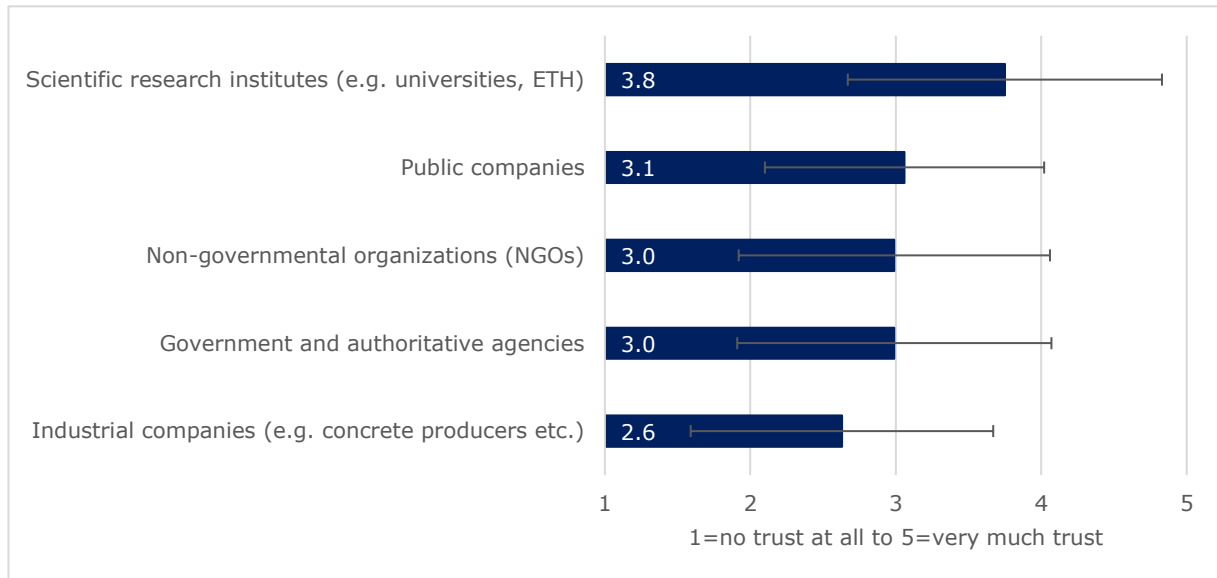


Figure 4: Trust in different stakeholders involved in the CO₂ capture and storage process

4.2.2 General CCTS/CCUS knowledge and support

At the beginning of the survey, we briefly introduced the Swiss climate goals and, thereof, the need for carbon reduction and removal efforts. We then provided an explanation of what CCTS/CCUS is, based on the definition by the FOEN, and asked them if they had already heard about it and if they would support it. In general, participants know only a little about CCTS/CCUS ($M=2.5$, $SD=0.9$). In comparison, they tended to support the implementation and operation of such technologies ($M=3.6$; $SD=0.9$).

4.2.3 Specific CCTS/CCUS pathways

4.2.3.1 First impression

After participants had time to look at the information provided about one of the two pathways, we asked them "What is your first impression of this pathway?" In the following, we report on the aspects that were mentioned by the participants of both pathways, as well as on issues that only apply to one of the two pathways.

Both pathways

In Table 8, we list the aspects that were mentioned by participants for both pathways. Overall, participants perceive it as a good ($n=179$), promising ($n=81$) and interesting ($n=35$) option to reduce CO₂ emissions. However, especially participants who were presented the information about the Icelandic pathways perceived the process also as complex ($n=30$); which was the case for 14 participants of the Swiss pathway. The contribution to the measures against climate change, namely CO₂ emission reduction, was also mentioned by 43 participants. However, 23 participants also questioned that it is only "fighting consequences" and not the source of the problem is addressed. Additionally, for some the costs are too high ($n=36$). Moreover, especially for the concrete pathway the problem of the "rebound effect" was mentioned; meaning that more concrete would be produced instead of reduced.

Table 8: Overview of participants' first impression for both pathways

Aspect	Total	Iceland	Switzerland
Good option	179	86	93
Promising	81	43	38
Complex	44	30	14

Measure against climate change (CO ₂ reduction)	43	19	24
Expensive	36	21	15
Interesting	35	16	19
Long-term negative impact for the environment	29	20	9
I don't know (if it will work/if it's a justifiable process)	28	14	14
Interim solution/ Fighting consequences and not addressing the source of the problem (CO ₂ emission reduction)	23	10	13
Questionable if CO ₂ balance at the end really positive	20	8	12
Unnecessary	18	12	6
Costs are low/can be lowered	14	5	9
Sceptical	13	4	9
Innovative	12	6	6
Questionable if there is no CO ₂ leakage from the underground /concrete	12	5	7
80%/90% is a good CO ₂ efficiency	12	1	11
Questionable if practically implementable (on a large scale)	11	2	9
Cannot be a single solution (mix of measures)	8	4	4
Limited storage potential	7	4	3
Rebound effect (higher CO ₂ production)	6	1	5
Permanent CO ₂ removal	5	1	4
Benefit: CO ₂ captured at a plant (side product)	3	2	1
Already applied projects (since 1996)	3	2	1
Good business model	3	2	1
Too technical	2	1	1
Safety issues	2	1	1

Icelandic pathway

As visible in Table 9, participants who were shown the information about the Icelandic pathway especially criticized the long transport to Iceland (n=44) and would prefer to store it locally (n=13). Further, participants also worried about the impacts on the environment at the storage site (n=13).

Table 9: Overview of participants' first impression for the Icelandic pathway only; listed are all aspects which were mentioned by more than one participant

Aspect	Frequency
Transport (to Iceland) not reasonable	44
Impact on the environment at storage site (underground / marine environment)	13
Why not storing it locally	13
Natural removal is better (e.g. afforestation)	3
Exporting the problems	3
Other solutions may be better (DACCS)	3
What happens after the mineralization	2
Natural events such as earthquakes lead to a release of the CO ₂	2

Swiss pathway

As visible in Table 10, participants who saw the pathway for the storage in concrete in Switzerland appreciated that the CO₂ concrete can be used to build streets and buildings (n=15), demolished concrete ('Abbaubeton') is recycled (n=10), and it is a local solution (n=6). 10 participants however had concerns about the transportation with the trucks.

Table 10: Overview of participants' first impression for the Swiss pathway only; listed are all aspects which were mentioned by more than one participant

Aspect	Frequency
Utilization	15
Why truck transport (and not train)	10
Recycle concrete	10
Local solution	6
CO ₂ released after demolition	4
Modified functionality of concrete	3
Good scalable	2
Circular economy	2
Who comes up with the financial resources	2
Safety for workers	2

4.2.3.2 Specific familiarity

As written above, the participants did not know a lot about CCTS/CCUS ($M=2.5$, $SD=0.9$). After presenting one of the two concrete pathways, we asked them whether they had already heard about this specific pathway. We saw that participants were even less familiar with these two pathways ($M=2.1$, $SD=0.9$) than CCTS/CCUS in general (see section 4.2.2). There was no significant difference between the Switzerland ($M=2.2$, $SD=0.9$) and Iceland ($M=2.0$; $SD=0.9$) pathway ($t(501)=-1.82$, $p=.07$).

4.2.3.3 Comprehension

Participants who saw the Swiss pathway answered on average 2.6 ($SD=1.1$) out of 4 questions correctly, and those who saw the Icelandic pathway 2.7 ($SD=1.1$) out of 4 questions. As visible in Table 11, they in particular struggled to understand that costs can be reduced through widespread application of the technology and that the final CO₂ balance is negative, thus CO₂ emissions are successfully removed. These results are in line with the findings of the qualitative analysis of people's first impression of the information (see section 4.2.3.1).

Table 11: Overview of the percentage of participants who correctly answered the four statements correctly; aggregated over both pathways and the pathways separately. Correct answers are highlighted in green.

Comprehension statements	Iceland	Switzerland	Total
Costs can be reduced through widespread application of the technology.	59.2%	58.9%	59.0%
It is a process that has never been used before.	84.7%	71.4%	78.3%
Through this process, all CO ₂ emissions that are difficult to avoid can be captured and stored in Switzerland.	63.0%	75.5%	68.9%
The process makes it possible to offset CO ₂ emissions that are difficult to avoid, also taking into account emissions during capture, transport, and storage.	62.6%	58.9%	60.8%

4.2.3.4 Specific acceptance (index)

We assessed participants' acceptance with the index introduced by Arning et al. (2020); asking if they perceive the process as useful, acceptable, necessary to offset CO₂ emissions that are difficult to avoid, necessary to achieve the climate goals of Switzerland, safe, and make sense. Further,

we asked the participants if the Icelandic/Swiss public should support it to then actually implement it, depending on the pathway they saw.

Aggregated over all statements and both pathways, there is a medium acceptance ($M=3.5$, $SD=0.92$). Thereby, the Swiss storage in concrete shows a significant slight higher acceptance than the storage in Iceland ($t(501)=-2.36, p=.02$); see Table 12. The Swiss pathway was rated higher with regards to all items except regarding the support by the local population. This indicates that when transporting CO₂ abroad, it is important for Swiss people that the local population accepts and supports the process.

Regarding the Icelandic pathway, we identified five significant effects of the independent variables on participants' acceptance (Annex B-5 and B-7). First, participants between 18-30 years old have a higher acceptance than participants between 55-66 years old. Second, the higher participants' climate change concern, the higher is their acceptance. Third, the higher their trust in the involved actors, the higher their acceptance. Fourth, the better participants understood the information, the higher was their acceptance. Fifth, participants with a Matura as highest degree have a higher acceptance than participants with an apprenticeship as highest degree.

Regarding the Swiss pathway, we identified five significant effects of the independent variables on participants' acceptance (Annex B-6 and B-7). First, the higher participants' climate change concern, the higher is their acceptance. Second, the higher their trust in the involved actors, the higher their acceptance. Third, the more right-wing a person's political views are, the higher their acceptance is. Fourth, the higher participants' general support and the lower their general familiarity, the higher their acceptance for the specific pathway.

Table 12: Acceptance index, separated by the two pathways as well as aggregated over both; from 1=strongly disagree to 5=strongly agree. The cell of the pathway with the higher value is highlighted in blue.

Acceptance index	Switzerland		Iceland		Both	
	Mean	SD	Mean	SD	Mean	SD
The process is useful.	3.77	1.16	3.54	1.13	3.65	1.15
The process is acceptable.	3.68	1.11	3.36	1.11	3.51	1.12
The process is necessary to offset CO ₂ emissions that are difficult to avoid.	3.57	1.14	3.34	1.12	3.45	1.13
The process is necessary to achieve Switzerland's climate goals.	3.63	1.17	3.37	1.18	3.50	1.18
The process must be supported by the [Icelandic or Swiss] population.	3.59	1.21	3.81	1.22	3.71	1.22
The process is safe.	3.30	1.05	3.11	0.99	3.20	1.02
The process is reasonable.	3.63	1.18	3.31	1.14	3.46	1.17
<i>Summative mean</i>	3.59	0.93	3.41	0.90	3.50	0.92

4.2.3.5 Specific support

The participants tended to support the pathways ($M=3.5$, $SD=1.1$). Whereby, storage in concrete in Switzerland was slightly more supported ($M=3.6$, $SD=1.0$) compared to storage in Iceland ($M=3.4$, $SD=1.1$); with a small significant effect ($t(501)=-2.26, p=.02$).

Regarding the Icelandic pathway, we identified four significant effects of the independent variables on participants' support (Annex B-5 and B-7). First, participants between 18 and 30, 43 and 54, and 67-100 had a higher support than participants between 55 and 66. Second, the higher participants' trust in the involved actors, the higher their support. Third, the more right-wing a

person's political views are, the higher their support is. Fourth, the higher participants' general support for CCTS/CCUS, the higher their support for the specific pathway.

Regarding the Swiss pathway, we identified six significant effects of the independent variables on participants' support (Annex B-6 and B-7). First, the higher participants climate change concerns, the higher their support. Second, the higher their trust in the involved actors, the higher their support. Third, the more right-wing a person's political views are, the higher their support is. Fourth, the higher participants' general support for CCTS/CCUS, the higher their support for the specific pathway. Fifth, the higher their familiarity with the pathway, the higher their support. Sixth, participants with a university degree showed higher level of support than participants with an apprenticeship as their highest educational degree.

4.2.3.6 Perceived risks

Regarding the Icelandic pathway, participants mostly worry about (i) the political dependencies which could lead to the failure of the project, (ii) Switzerland exporting its problems to Iceland (ethical question), and (iii) larger natural events, such as volcanic eruptions or earthquakes, that could lead to CO₂ leakage (see Table 13). These risks are perceived as more severe, the higher participants climate change concerns or the lower their trust in the actors involved in the pathway (Annex B-7).

Regarding the Swiss pathway, participants are mainly worried about the fact that the process support the use of concrete instead of switching to other more sustainable building materials. Further, they are not sure if the CO₂ will be stored in the concrete forever, i.e. demolition of buildings or streets (see Table 13). These risks are perceived as more severe, the higher participants climate change concerns or the lower their trust in the actors involved in the pathway (Annex B-7).

Table 13: Overview of the perceived risk assessed in our public survey (column 2), listed in descending order with respect to the mean value. In blue highlighted are the statements which were identical for both pathways. Corresponding Figures in Annex B-10.

Perceived risk		Mean	SD
Iceland	The geopolitical dependencies could lead to the failure of the project.	3.51	0.93
	Switzerland exports its problems to Iceland.	3.50	1.18
	Larger natural events such as earthquakes or volcanic eruptions can lead to the escape of CO ₂ .	3.42	0.99
	CO ₂ leakage during the transport.	3.27	1.07
	CO ₂ leakage from the rock formation to the surface	3.24	0.99
	The CO ₂ storage has negative effects on the underground ecosystem (e.g., drinking water pollution, living beings, biodiversity).	3.17	0.97
	The process is harmful to human health.	2.55	0.92
Switzerland	The process supports the use of concrete instead of switching to other more sustainable building materials.	3.43	1.09
	The CO ₂ storage is not forever (e.g. demolition of buildings).	3.36	1.02
	CO ₂ leakage during the transport.	3.09	1.00
	The CO ₂ storage in concrete has negative effects on the environment.	2.72	1.05
	The process is harmful to human health.	2.57	0.92

4.2.3.7 Perceived benefits

Regarding the Icelandic pathway, participants agreed most that the up-scaling of this process will lead to new jobs, the process allows Switzerland to achieve its climate goals, and the industry takes responsibility for its emissions (Table 14). These benefits are significantly less valued by participants aged between 55 and 66, compared to 18-30 or 43-54 years old participants (Annex B-5). In comparison, these benefits are more positively perceived, the higher participants' trust in the actors involved and the more right-wing their political views are (Annex B-7).

Regarding the Swiss pathway, participants agreed most with that this is a local solution to remove CO₂ emissions, the process allows Switzerland to achieve its climate goals, and the upscaling process might lead to new jobs (Table 14). These benefits are more positively perceived, the higher participants' trust in the actors involved, the better they understand the information, and the higher their general support of CCTS/CCUS is (Annex B-7).

Comparing the two pathways, the storage in concrete was better perceived in terms of the industry taking responsibility for its emissions and the less invasive process with regards to nature. Further, the Swiss pathway is perceived as more likely to increase people's environmental awareness (Table 14).

Table 14: Overview of the perceived benefits assessed in our public survey (column 1), listed in descending order with respect to the mean value. In blue highlighted are the statements which were identical for both pathways. Corresponding Figures in Annex B-11.

	Perceived benefits	Mean	SD
Iceland	The up-scaling of this process leads to new jobs.	3.56	0.94
	The process increases the chance of achieving Switzerland's climate goals.	3.53	1.06
	The industry participates in the measures to reduce CO ₂ emissions and, thus, takes responsibility for its emissions.	3.14	1.00
	The process increases people's environmental awareness.	2.79	1.19
	The process does not require any intervention in nature.	2.31	1.15
Switzerland	It is good that it is a local solution to reduce CO ₂ emissions.	3.71	1.07
	The process increases the chance of achieving Switzerland's climate goals.	3.64	1.11
	The up-scaling of this process leads to new jobs.	3.54	1.00
	The industry participates in the measures to reduce CO ₂ emissions and, thus, takes responsibility for its emissions.	3.38	1.05
	The process increases people's environmental awareness.	3.19	1.17
	The technology has a low risk of CO ₂ leakage.	3.17	0.97
	The process does not require any intervention in nature.	3.09	1.10

4.2.3.8 Design perception

Aggregated over all design characteristics, the infographic was significantly better perceived than the long text (Annex B-8). As visible in Table 15, participants rated all factors the highest for the infographic, especially perceiving it as informative and well structured. The Q&A was second best perceived.

Table 15: Overview of participants' design perception differentiated by the four communication products. [Mean (Standard deviation)]. Dark blue highlighted are the cells with the highest means per design characteristic and light blue the second highest mean. The corresponding figure is listed in Annex B-9.

Design perception	Infographic	Q&A	LinkedIn	Text	Summative mean
Informative	3.82 (0.87)	3.66 (0.98)	3.54 (1.06)	3.67 (0.98)	3.68 (0.97)
Understandable	3.53 (1.02)	3.36 (1.10)	3.41 (1.08)	3.31 (1.06)	3.41 (1.07)
Structured	3.77 (0.93)	3.60 (1.03)	3.59 (1.05)	3.45 (0.99)	3.61 (1.00)
Clear	3.74 (0.93)	3.59 (1.08)	3.49 (1.10)	3.34 (0.99)	3.55 (1.04)
Attractively designed	3.68 (1.01)	3.38 (1.10)	3.19 (1.11)	3.20 (1.04)	3.37 (1.08)
Trustworthy	3.56 (0.98)	3.35 (1.11)	3.31 (1.17)	3.31 (1.05)	3.39 (1.08)

4.2.3.9 Further questions

After participants had time to look at the information provided about one of the two pathways, we asked them "What else would you like to know about the pathway?" Although the question was optional, 68 participants who received information about the Icelandic pathway and 51 participants who were informed about the Swiss pathway indicated questions they had. The topics these questions covered are listed in Table 16.

Regarding both pathways, participants want to i) know more about the risks and safety regarding the entire pathways; ii) receive more details about the processes (e.g., capture process); iii) learn about the impacts on the environment; iv) have a more precise estimate of the costs; and v) know which alternative pathways exist to reduce or capture and store CO₂ (plus a comparison of all measures). In addition, some participants would like to have an overview of all the players involved and who among them is making money.

Participants who received the Icelandic information further wanted to know why exactly Iceland was chosen as a storage site, what the risks and safety measures of the CO₂ transportation are, and the effects on the underground/marine environment. Further, some participants also wondered if the people in Iceland accept and support the project.

In comparison, participants who saw an information product related to the Swiss pathway asked if the CO₂ will be permanently stored in concrete, what will happen with the CO₂ after the demolition, and if the functionality of the concrete changes with a higher CO₂ concentration. Some participants also wondered why alternative materials (e.g., wood) were not used instead.

Table 16: Frequency of the topics participants' questions address [only listed those mentioned by more than two participants]

Topics addressed by the questions	Frequency
What are the risks and overall safety regarding the entire pathways?	25
General further information [details about the processes]	19
What are the impacts on the environment ?	13
What are the precise costs ?	12
Is the CO ₂ permanently stored in concrete?	9
What happens with the CO ₂ after the demolition ?	9
What are the risks and safety measures of the CO ₂ transport ?	6
What is the final positive effect for the environment?	6
Why do we have to transport the CO ₂ to Iceland ?	5

What are alternative pathways to capture and store CO ₂ ?	5
Comparison to other CO ₂ reduction measures	5
Who are the involved actors and who benefits/ earns ?	4
What is the contribution of this specific pathway to the overall CO₂ reduction target ?	4
What are the effects on marine animals and environment?	3
What are the accident quotes for CO ₂ leakage?	3
What is the public opinion and acceptance in Iceland?	3
What is the functionality of the concrete (load bearing capacity)?	3

4.2.3.10 Local storage acceptance [only Icelandic pathways; n=262]

Aggregated over all statements, participants had a medium acceptance to store the CO₂ locally (M=3.0, SD=1.1). Although, participants rather disagreed that a local storage would cause any problems, they would protest against it (Table 17). Further, the higher participants' trust in the actors involved in the process and their general support of CCTS/CCUS the higher is their acceptance to store the CO₂ locally (B-15). Further, men also had a higher acceptance for local CO₂ storage than women (B-15). The other socio-demographic and personal factors show no significant effects.

Table 17: Local acceptance index, ranging from 1=strongly disagree to 5=strongly agree. The third and fourth statements were recoded. See also Annex B-12.

Local acceptance index	Mean	SD
I would accept the construction of a storage site in my neighbourhood.	2.87	1.27
I don't think a storage site in my neighbourhood would cause any problems.	2.82	1.22
I would be concerned if a storage site were built in my neighbourhood.	2.98	1.28
I would protest the construction of a storage site in my neighbourhood.	3.42	1.34
<i>Summative mean</i>	<i>3.02</i>	<i>1.1</i>

4.2.4 Evaluation of the transportation means

Overall, participants most supported the transportation of CO₂ with train (M=3.7, SD=1.3) and pipeline (M=3.3, SD=1.3), followed by the ship (M=2.8, SD=1.3) and truck (M=2.4, SD=1.2); Annex B-13. As visible in Figure 5, trucks were especially perceived as less environmentally friendly. In comparison, trains were perceived as the safest, environmentally friendliest, and politically implementable option. Only regarding the efficiency were pipelines better rated.

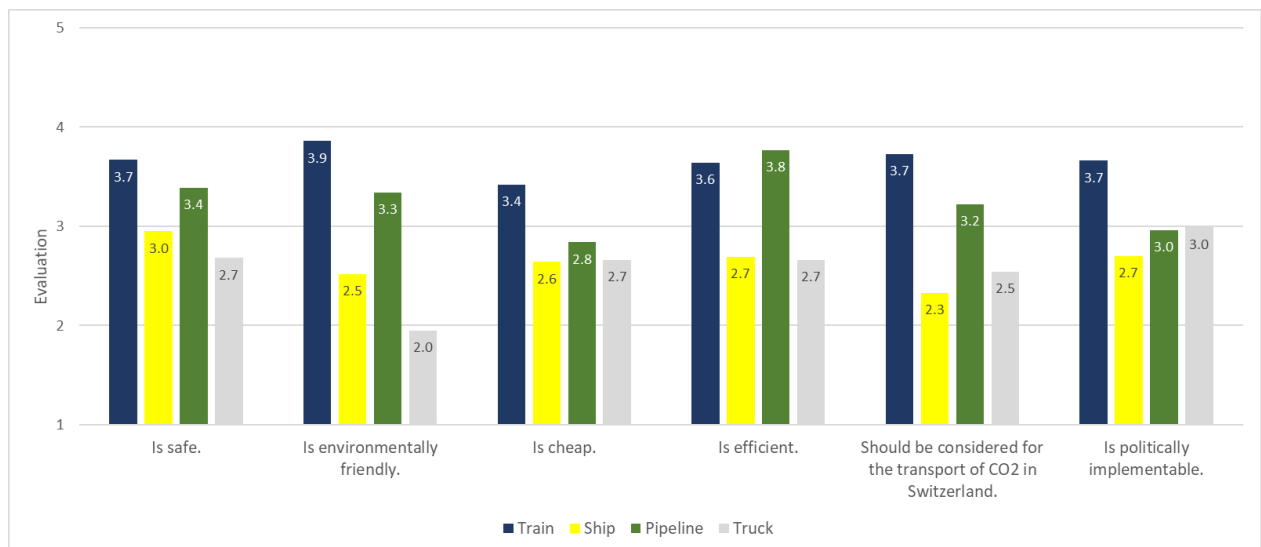


Figure 5: Evaluation of the transportation means with regards to different characteristics.

The statistical analysis showed that people who received information about the Iceland pathway evaluated ships significantly better than people who saw the Switzerland pathway ($t(501)=2.90$, $p=.004$). In comparison, people who saw the Switzerland pathway perceived trucks for the CO₂ transportation significantly better than people who saw the Iceland pathway ($t(501)=-4.87$, $p<.001$). There are no significant differences between the pathways regarding trains and pipelines (see Figure 6).

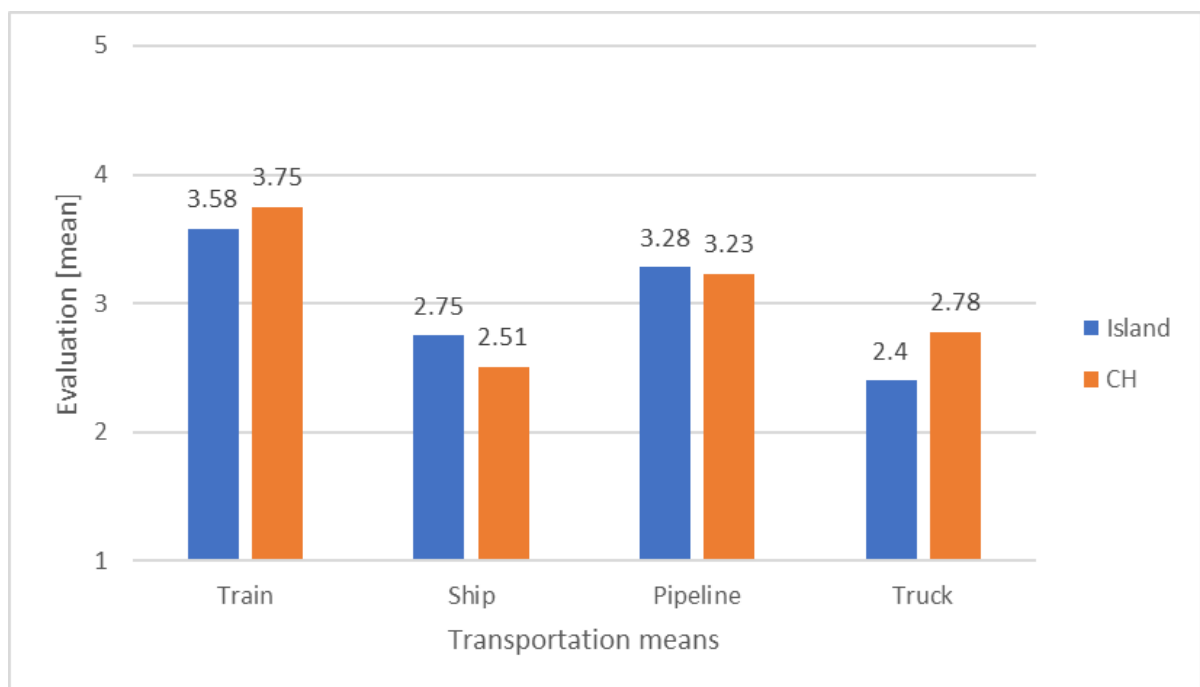


Figure 6: Participants' overall evaluation of the four transportation means, divided by the two CO₂ storage pathways
[1="I do not agree at all", 5="I fully agree"]

4.2.5 Evaluation of the origin of CO₂

As visible in Figure 7, people support CO₂ storage in Switzerland the most when the CO₂ comes from Switzerland; followed by neighbouring countries or Europe in general. Not supported is the storage when the CO₂ comes from outside Europe or the origin is not communicated. The detailed values are listed in Annex B-14.

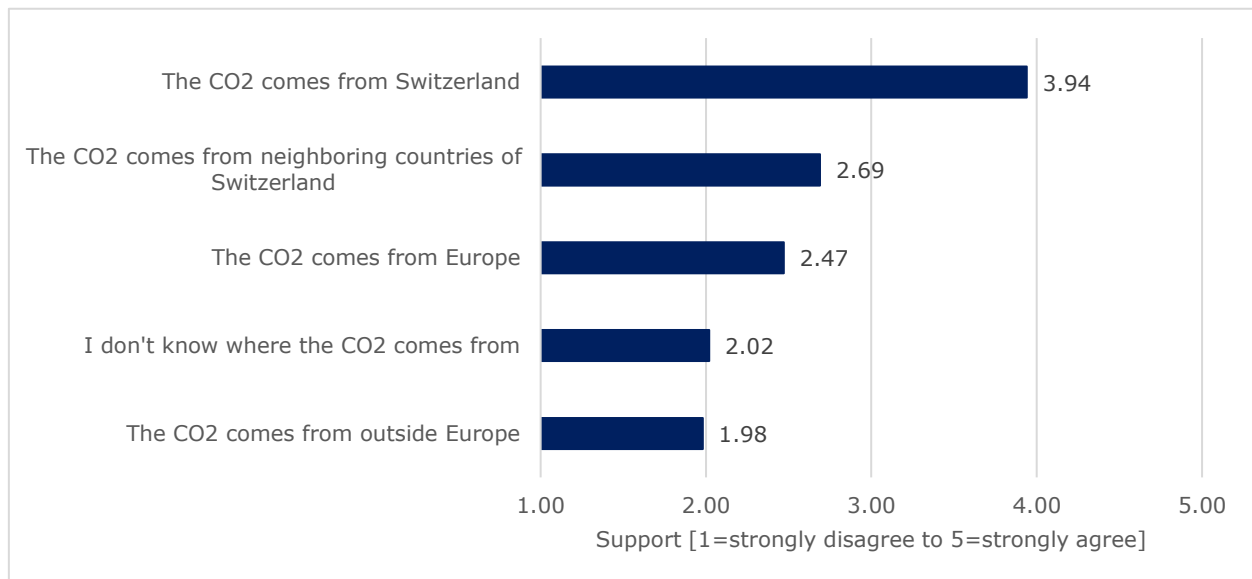


Figure 7: Support of CO₂ storage in Switzerland, when the CO₂ comes from the sources listed.

4.2.6 Communication preferences

We also asked participants in which format and via which channel they would like to receive information about these or similar pathways in the future. As visible Figure 8, the most preferred are reports on TV (57.9%) or short explanatory videos (53.8%). Least preferred were social media (17.3%) posts and podcasts (10.7%).

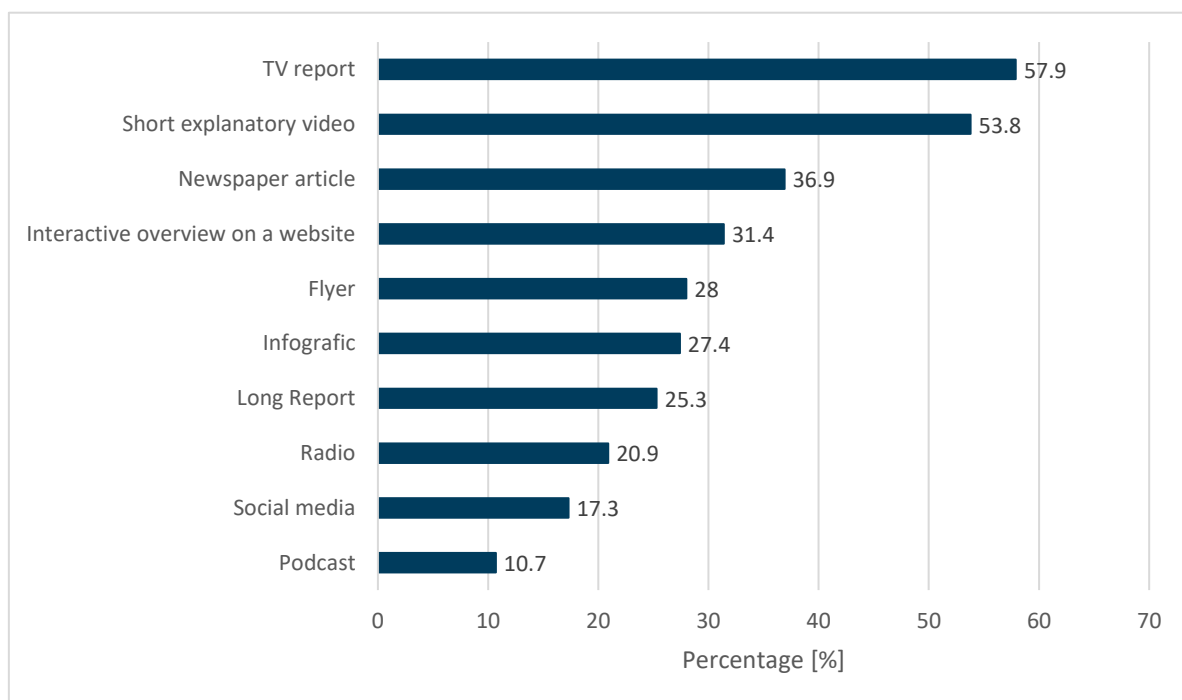


Figure 8: Preference for communication formats and channels

Regarding the source of the information, participants wanted to receive mainly from scientists (75.7%), federal authorities (48.9%), or NGOs (45.5%). Less preferred were industry representatives (23.3%), politicians (15.1%), and activists (5.0%); see Annex B-15.

5 Discussion

Our six focus groups and the online survey (N=503) allowed us to answer our two overarching research questions: (i) What is the Swiss public's knowledge, support, perceived risks and benefits, and acceptance of the two CCTS/CCUS pathways envisioned in DemoUpCARMA? (section 5.1); and (ii) How can understandable communication be designed to adequately inform the public about CCTS/CCUS, taking into account their preferences and needs? (section 5.2).

5.1 Public perception, acceptance and support of CCTS/CCUS

A study in 2008 showed that the public is not familiar with CCTS/CCUS and their knowledge is limited (Wallquist et al., 2009); which has not changed in the last decade (Wenger et al., 2021). We have also shown that familiarity with CCTS/CCUS in general and with the two pathways in particular is low. However, when giving information about the need for CCTS/CCUS, opinion can shift toward support (Shackley et al., 2004). This is consistent with our findings that specific familiarity can increase support for a pathway.

5.1.1 Positive drivers of acceptance and support

We identified several factors that can increase public acceptance and support, confirming the results of previous studies and providing new insights.

Merk et al. (2022) showed that Norwegians have a higher acceptance of CCTS/CCUS when the CO₂ is domestically sourced and not foreign. This is line with our results that Swiss people have a higher acceptance when the CO₂ comes from Switzerland. In comparison, for German people there is no difference whether the CO₂ is captured in another country or Germany itself (Merk et al., 2022).

Indicating that CCTS/CCUS is part of an overall strategy/measure portfolio increases people's support (Shackley et al., 2004; Oltra et al., 2010). This is in line with the insights from our focus groups, where we showed that people worry that other measures will be replaced by CCTS/CCUS.

Further, a higher level of trust in industry, science, and government increased the level of public support (Jobin & Siegrist, 2020). We can support this finding with our results and even can show that higher level of trust does not only increase public support but also acceptance and the positive perception of the benefits. Further, participants with high level of trust also perceive the risk as less worrying.

von Rothkirch and Ejderyan (2021) further concluded that local factors (e.g., environmental justice) can increase or decrease public's acceptance. With our results we support this conclusion, since Swiss people do not want to simply get rid of their own problems by passing it on to another country. Thus, for them it is important that, if a technology is implemented, the local population (in our case Iceland) supports it.

What we further showed with our study is that people with more right-wing views have higher level of acceptance and support, especially regarding the Swiss pathways. Additionally, people with high level of climate change concerns also support and accept the pathways more.

5.1.2 Negative drivers of acceptance and support

We identified several factors that can decrease public acceptance and support, which were also identified in other studies and cultural contexts. First, perceived risks and tampering with nature

decreases acceptance (Jobin & Siegrist, 2020). This is in line with our insight that the Icelandic pathway was perceived as an intervention in nature and, thus, had a lower overall support compared to the Swiss pathway.

Second, preferences for other climate mitigation measures such as energy efficiency efforts or the upscaling of renewable energy can also lead to lower support (Oltra et al., 2010). Also, in our focus groups and public survey, we could show that people would prefer that CO₂ is not stored in concrete but that the corresponding industry sector invests in sustainable materials (replacing concrete).

Third, when the government is perceived as having a special (own) interest, support can be inhibited (Oltra et al., 2010). In our focus groups, the people also discussed or asked which stakeholders benefit in which way. Thus, the interests of the involved actors must be transparently communicated.

Fourth, mentioning the costs of deploying CCTS/CCUS can lead to lower support (Whitmarsh et al., 2019). This is in line with our results that people's first impression was that the costs are quite high. We recommend to discuss the costs in the context of the broader energy system transformation so that people have a comparable basis. Further, they wonder if the entire pathway (transportation to and storage in Iceland) actually reduced CO₂.

Fifth, the investigations in Iceland (storage underground in basalt) showed that the public also has concerns about ocean acidification, land protection issues, and the high water consumption (Grettisson, 2023). Also, the Swiss people are worried about the consequences for and interventions in the environment; as identified in the focus groups and the online survey.

5.1.3 Benefits, risks and preferred transportation means

We compared the perceived benefits that have been identified in previous studies, with the benefits our participants in the focus groups and public survey came up with (Annex B-16). In addition to those from past studies, we show that people perceived the following benefits for CCTS/CCUS: i) trigger to increase society's environmental awareness; ii) solution that can be applied in different countries; iii) the industry helps and takes responsibility; iv) politically easier to get accepted because no personal reduction is needed; v) these pathways can increase the chance to actually reach our net-zero goals; and vi) it allows long-term storage of the emitted CO₂.

Regarding the perceived risks, we, in addition to those assessed in previous studies, identified the following (Annex B-17): i) political lobbying; ii) inertia of the political system, which will slow down the upscaling; iii) no incentive to emit less CO₂ (e.g., sufficiency, decarbonization); iv) large natural events such as earthquakes or volcanic eruptions can lead to CO₂ leakage; v) construction industry has no incentive to reduce CO₂ footprint; vi) neglect of sustainable substitutes (concrete pathway); and vii) wrong investment, the financial resources are needed for other measures.

Further risks and benefits mentioned by the participants were process-specific. This implies that some risks and benefits are only perceived for certain technologies/pathways and that their relevance can vary from context to context. Therefore, it is crucial to assess for each project separately which risks and benefits are important for the affected people.

Regarding the transportation means, Wallquist et al. (2012) showed that options without pipelines are preferred over options with a (CO₂) pipeline. We showed that trains are preferred over pipelines, ships, and trucks. However, also the pipeline was overall perceived well, in particular regarding efficiency. This is in line with the insights for Hydrogen transportation, where the public prefers transportation via pipelines over trucks (Hämmerli, 2019).

5.2 User-centred communication

Acceptance for a technology/process is higher when people receive adequate technical background information (Offermann-van Heek et al., 2020) and information which addresses their concerns (Dechezleprêtre et al., 2022). This is in line with our findings that people's support for CCTS/CCUS processes is higher if they are familiar with them. Thus, it is key to provide understandable and clear information to the public, enabling them to build informed opinions about CCTS/CCUS. We thus derived five specific recommendations for public communication from the results of our studies, which are described in detail in the commentary by Eberenz et al. (2023):

- 1. *Establishing the context***
- 2. *Assessing public information needs continuously***
- 3. *Providing hierarchical information***
- 4. *Providing specific examples***
- 5. *Providing expert opinions***

We further showed that people perceive infographics the best, followed by Q&As, LinkedIn posts, and a written text. Since people further prefer to receive information on CCTS/CCUS as TV reports, short explanatory videos, and newspaper articles, we recommend to distribute the infographics via these channels.

6 Conclusion and outlook

We assessed Swiss public perception, familiarity, acceptance, and support of the two pathways envisioned in DemoUpCARMA – storage in concrete in Switzerland and storage in basalt in Iceland. Further, we evaluated different communication products to provide recommendations on how to best inform the public about CCTS/CCUS. Our results, among others, indicate that i) Swiss people are not familiar with the two pathways and CCTS/CCUS in general; ii) acceptance and support is driven by various personal factors (e.g., the higher people's climate change concerns or trust in the involved actors, the higher their acceptance and support); iii) perceived benefits and risks can be very process-specific; iv) trains are perceived as the environmental friendliest transportation mean; and iv) infographics are preferred over written text. Our insights should support institutions and entities responsible for the communication with the public to inform them adequately about CCTS/CCUS projects, taking into account their attitudes, concerns, and preferences.

Future research is needed to regularly assess public perception in order to identify emerging concerns or tipping points regarding the support of CCTS/CCUS. For instance, when people experience the effects of climate change more intensively, their support may increase in the future. Further, the societies along the entire CCTS/CCUS should be involved, thus in the pathway where CO₂ is stored in geological reservoirs in Iceland the population there should be considered too (e.g., online survey). Thereby, also cultural differences or commonalities can be identified, which in turn may influence the effectiveness of different communication approaches. We thus motivate other research groups around the world to contribute to the ongoing research efforts on the social perspective of CCTS/CCUS and, consequently, to enable a societally sustainable upscaling of these technologies, which is needed to reach the 2°C climate goal.

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9 Annex

Annex A – Outputs Focus Groups

A-1: Procedure of the focus groups

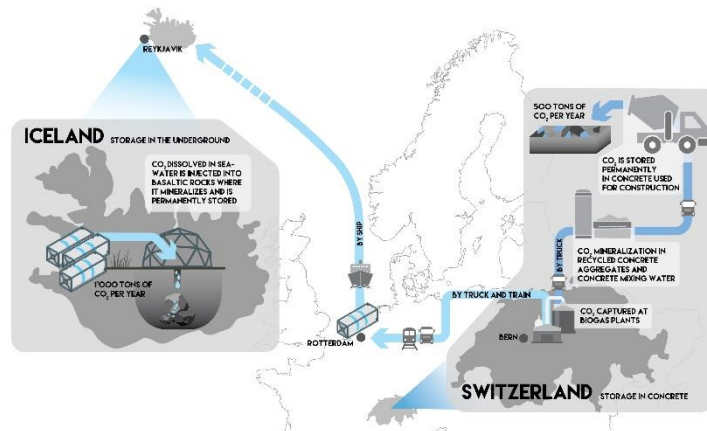
The following table shows the procedure of the focus groups. The questions are to be understood as guiding questions and varied slightly depending on the dynamics of the discussion.

Phase	[min]	Inhalt
Phase 0 	5	Einführung - Informationsblatt kurz vorstellen [da bereits per Mail erhalten] & Einverständniserklärungen ausfüllen lassen - Ziele der Fokusgruppen und grober Ablauf vorstellen [ausgedrucktes A3] - Spielregeln der Diskussion
Phase 1 	5	Vorstellungsrunde [ice breaker question] - Bitte stellen Sie sich kurz vor, indem Sie Ihren Namen sagen und eine kurze Antwort auf folgende Frage geben: Welche technologische Erfindung (von Auto, über Föhn zu Küchenmaschinen) hatte in Ihrem bisherigen Leben den grössten positiven Einfluss und weshalb?
Phase 3 	20	Entdeckungsphase [Exploring phase] <i>1) Einführung Energiestrategie</i> <i>[A3-Übersicht der Energiestrategie zeigen]</i> Damit die Energieversorgung der Schweiz trotz wirtschaftlichen, technologischen oder global-politischen Veränderungen gesichert werden kann und die Schweiz auch für unvorhersehbare Ereignisse gewappnet ist, hat der Bundesrat die Energiestrategie 2050 entwickelt. Die Schweiz soll hiermit nicht nur den hohen und guten Energieversorgungsstandard halten können, sondern auch die energiebedingte Umweltbelastung reduzieren können und bis 2050 klimaneutral werden. Dies bedeutet, dass die Schweiz unter dem Strich keine Treibhausgasemissionen mehr ausstossen darf. Um dieses Ziel zu erreichen, und somit auch die Vereinbarungen des Pariser Klimaabkommens einzuhalten, gibt es verschiedenste Bestrebungen. Zwei dieser Bestrebungen sind schärfere Massnahmen, um den Energieverbrauch und die CO2-Emissionen zu senken und die

Restemissionen durch Abscheidungs- und Einlagerungstechnologien sowie Negativemissionstechnologien (NET) zu kompensieren.

2) Entdeckung der Pfade

[Zeigen der A3-Infografik mit beiden Pfaden]



Für beide Pfade:

- [Einen Teilnehmenden bitten]: Können Sie in Ihren eigenen Worten kurz beschreiben, was Sie auf der Grafik sehen (zuerst linken Pfad)?
- [Andere Teilnehmenden]: Habt ihr irgendwelche Ergänzungen? Etwas das ihr anders verstanden habt?
- Haben Sie bereits von diesen Möglichkeiten gehört? Wenn ja, was genau wussten Sie/ wissen Sie bereits?
- Wo haben Sie davon gehört, gelesen oder gesehen (z. B. Medien, Arbeit, Freunde)?

2) Gemeinsames, korrektes Verständnis schaffen

- Kurz in wenigen Sätzen erklären, wie die beiden Prozesse funktionieren:
Für beide Pfade wird das CO₂ bei einer Biogasanlage in Bern eingefangen und dann jedoch in zwei unterschiedlichen Prozessen gespeichert.

Pfad 1: CO₂-Speicherung in Island

Im Pfad 1 wird das CO₂ mit dem Lastwagen und Zug nach Rotterdam transportiert. Anschliessend wird das CO₂ mit dem

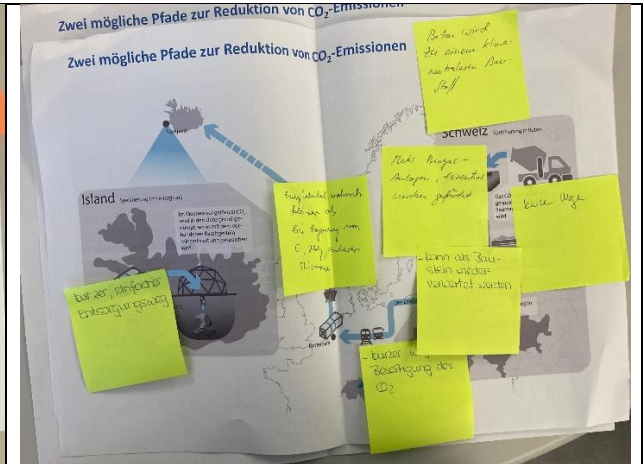
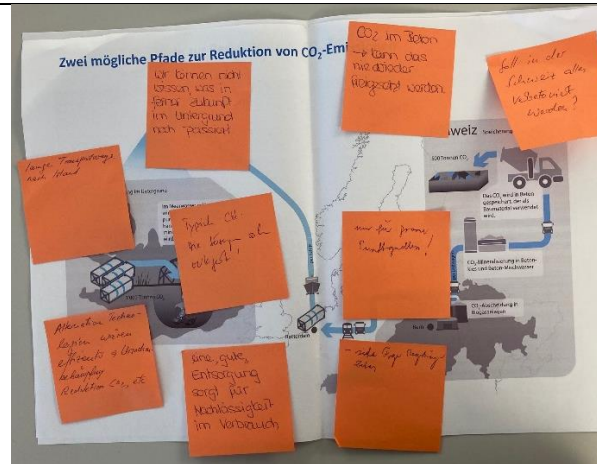
		Schiff nach Island transportiert, wo es in den Untergrund gepumpt wird. Im Untergrund mineralisiert das CO₂ dank eines neuen Verfahrens zu Stein. (Transport und permanente Speicherung von CO₂ in einem geologischen Reservoir im Ausland.) Pfad 2: CO₂-Speicherung in Schweizer Beton Im Pfad 2 wird das CO₂ durch ein neues technisches Verfahren mineralisiert und zu Beton verarbeitet. Der Beton kann anschliessend für Gebäude, Strassen etc. benutzt werden. Alle diese Schritte finden in der Schweiz statt. (Nutzung und permanente Speicherung von CO₂ in neuem und recyceltem Beton in der Schweiz mittels eines neuen Verfahrens.)
Phase 4 	20	Reflection phase [Reflexionsphase] <i>[Drei ausgedruckte Infografiken in die Mitte legen und den Teilnehmenden Post-its mit drei verschiedenen Farben geben: blau (offene Fragen), grün (Nutzen), rot (Risiken, Sorge, Anliegen) → jeweils auf separates A3]</i> 1) Wissenslücken und Offene Fragen - Welche Fragen würden Sie gerne einem Experten zu diesen Pfaden stellen? Auch in Bezug auf Aspekte, die noch nicht klar sind hinsichtlich Einfangen, Transportieren und Speichern des CO₂. 2) Nutzen & Risiken - Welche Nutzen und Risiken/Sorgen/Anliegen sehen/haben Sie bezüglich der beiden Pfade? <i>[Wenn Sie nicht viel nennen, Nutzen und Risiken aus der Literatur zeigen: Nutzen: europäische Zusammenarbeit, CO₂-Ziele erreichen, Reduktion nicht vermeidbarer Emissionen, nachhaltige Nutzung, Inländische Arbeitsplätze Risiken: andere Massnahmen werden vernachlässigt, Grundwasserverschmutzung, induzierte Erdbeben, Umweltschäden, Leck führt zu CO₂-Ausstoss, Transport unsicher, Infrastruktur kostspielig, Verfahren braucht viel Energie, unbekannte Risiken, keine Akzeptanz von der Bevölkerung, politische Hürden]</i> - Welche der genannten Risiken sind für Sie akzeptabel und welche nicht? [Hacken für akzeptable Risiken und Blitz für nicht akzeptable]. - Welche Nutzen sind für Sie besonders wichtig? [Sternchen auf Post-it]
Phase 5 	10	Conclusion [Fazit] - Danke vielmals für Ihre aktive Teilnahme. Als Abschluss würde ich gerne noch eine Runde machen, in welcher jede Person in ein bis zwei Sätzen zusammenfasst, welche Haupteckentnis sie/er aus der Diskussion mitgenommen hat. Was würden Sie nun zuhause oder in der Arbeit erzählen?

A-2: Outputs of the six focus groups

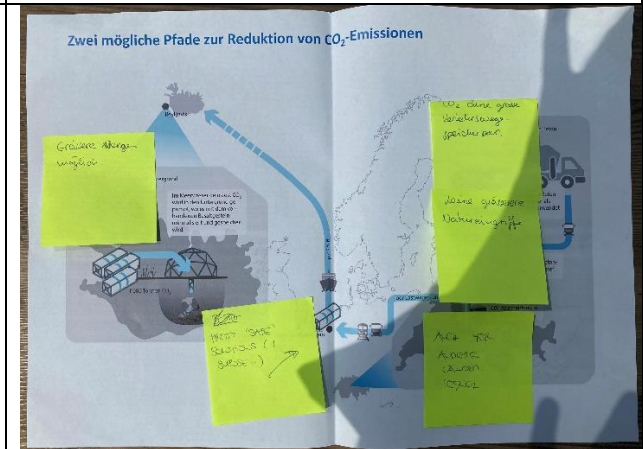
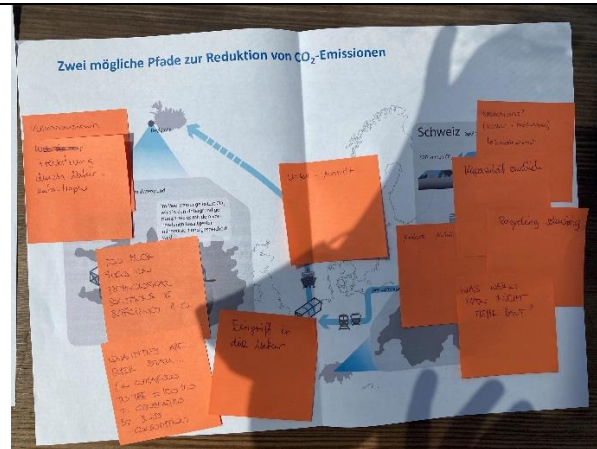
In the following Table the outputs of the six focus groups are listed, sorted by open questions, perceived risks, and perceived benefits.

	Open Questions	Perceived risks	Perceived benefits
Focus Group 1			
Focus Group 2			

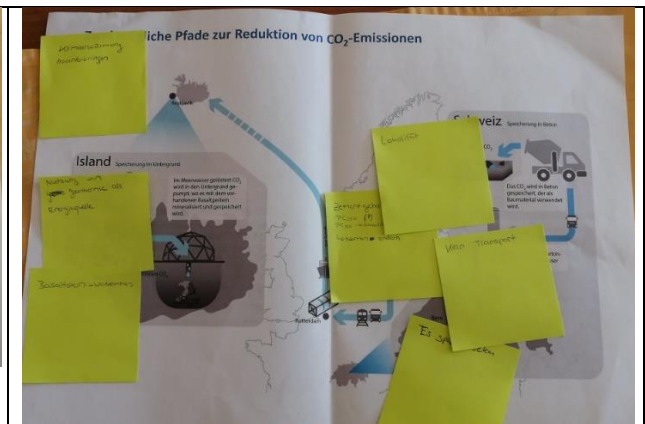
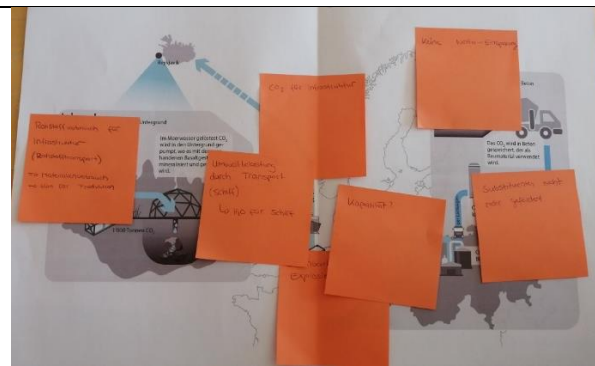
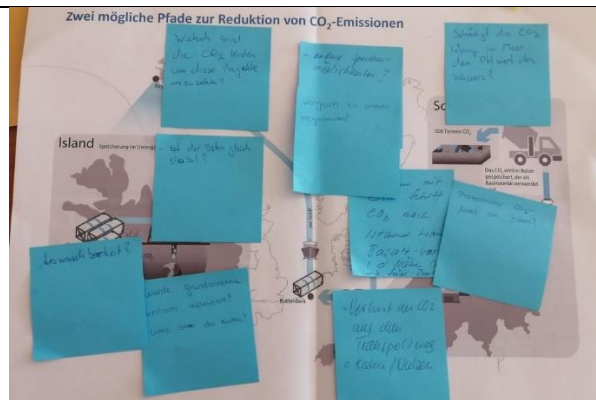
Focus Group 3



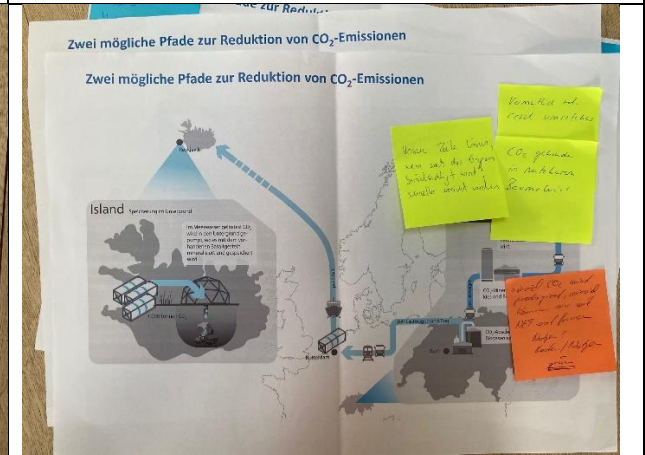
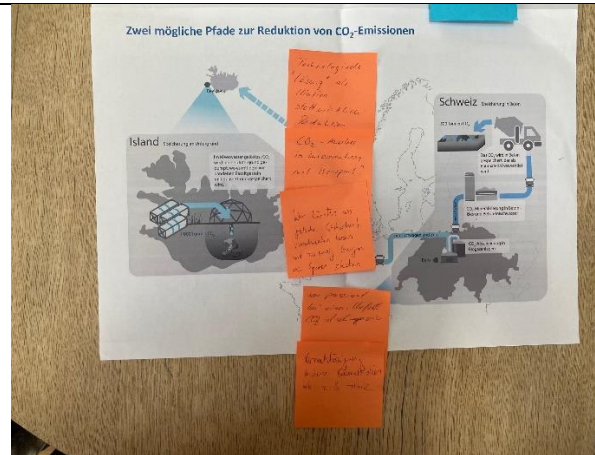
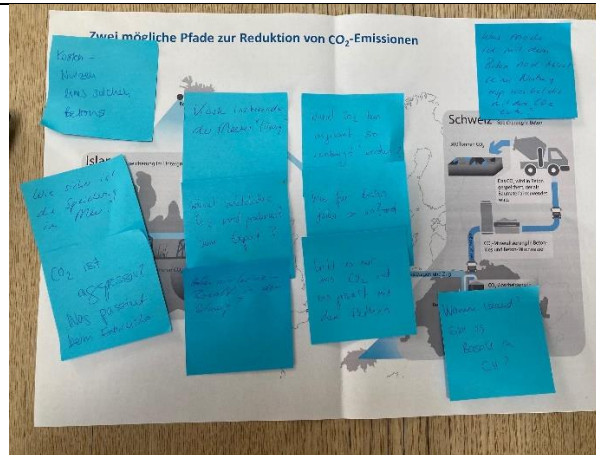
Focus Group 4



Focus Group 5



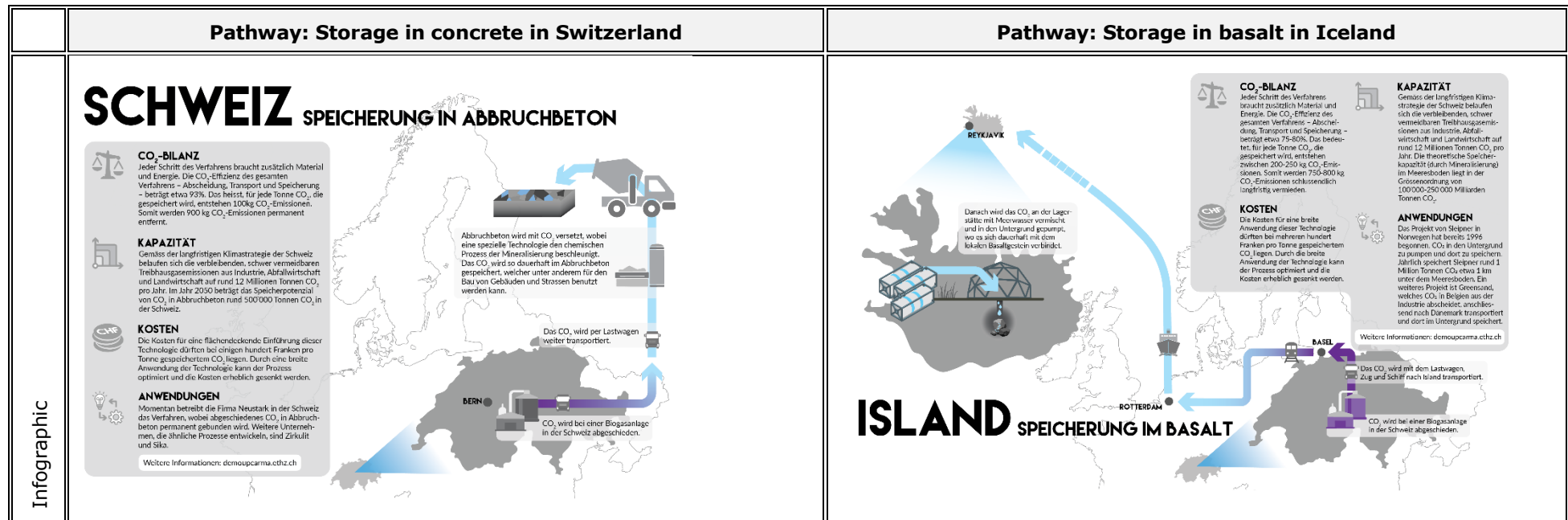
Focus Group 6



Annex B – Outputs Online Survey

B-1: Communication products

In the following table, the eight communication products we tested are listed. We thereby addressed for both pathways as well as for all versions the same four topics: i) CO₂ balance along the entire chain; ii) storage capacity; iii) costs; and iv) comparable projects.



Writen text	Im folgendem Text erhalten Sie weitere Informationen zu diesem Verfahren. Bitte lesen Sie den Text zuerst in Ruhe durch, bevor Sie die weiteren Fragen beantworten. Gemäss der langfristigen Klimastrategie der Schweiz belaufen sich die verbleibenden, schwer vermeidbaren Treibhausgasemissionen aus Industrie, Abfallwirtschaft und Landwirtschaft auf rund 12 Millionen Tonnen CO2 pro Jahr. Das oben beschriebene Verfahren der Speicherung von CO2 in Abbruchbeton hat dabei ein Speicherpotenzial im Jahr 2050 von rund 500'000 Tonnen CO2 in der Schweiz. Die Kosten für eine flächendeckende Einführung dieser Technologie dürften bei einigen hundert Franken pro Tonne gespeichertem CO2 liegen. Durch eine breite Anwendung der Technologie kann aber der Prozess optimiert und die Kosten gesenkt werden, Die CO2-Effizienz des gesamten Verfahrens - Abscheidung, Transport und Speicherung - beträgt etwa 90%. Das heisst, für jede Tonne CO2, die gespeichert wird, entstehen 100kg CO2-Emissionen. Somit werden 900 kg CO2-Emissionen permanent entfernt. Das Verfahren wird momentan von Neustark in der Schweiz betrieben, wobei abgeschiedenes CO2 im Beton gebunden wird. Weitere Unternehmen, die ähnliche Prozesse entwickeln, sind Zirkulit und Sika.	Im nachfolgendem Text erhalten Sie weitere Informationen zu diesem Verfahren. Bitte lesen Sie den Text zuerst in Ruhe durch, bevor Sie die weiteren Fragen beantworten. Gemäss der langfristigen Klimastrategie der Schweiz belaufen sich die verbleibenden, schwer vermeidbaren Treibhausgasemissionen aus Industrie, Abfallwirtschaft und Landwirtschaft auf rund 12 Millionen Tonnen CO2 pro Jahr. Die theoretische Speicherkapazität durch Mineralisierung im Meeresboden liegt in der Größenordnung von 100'000-250'000 Milliarden Tonnen CO2. Die Kosten für eine breite Anwendung dieser Technologie dürften bei einigen hundert Franken pro Tonne gespeichertem CO2 liegen. Durch die breite Anwendung der Technologie kann aber der Prozess optimiert und die Kosten gesenkt werden. Die CO2-Effizienz des gesamten Verfahrens - Abscheidung, Transport und Speicherung - beträgt etwa 75-80%. Das bedeutet, für jede Tonne CO2, die gespeichert wird, entstehen zwischen 200-250 kg CO2-Emissionen. Somit werden 750-800 kg CO2-Emissionen schlussendlich langfristig vermieden. Ähnliche Verfahren werden bereits in anderen Projekten angewendet. Sleipner in Norwegen hat 1996 begonnen, CO2 in den Untergrund zu pumpen und dort zu speichern. Jährlich speichert Sleipner rund 1 Million Tonnen CO2 etwa 1 km unter dem Meeresboden. Ein weiteres Projekt ist Greensand, welches CO2 in Belgien aus der Industrie abscheidet, nach Dänemark transportiert und dort im Untergrund speichert.

Q&A	In dem folgenden Q&A erhalten Sie weitere Informationen zu diesem Verfahren. Bitte lesen Sie das Q&A zuerst in Ruhe durch, bevor Sie die weiteren Fragen beantworten. Was ist die gesamte CO2-Bilanz des Verfahrens? Jeder Schritt des Verfahrens braucht zusätzlich Material und Energie. Die CO2-Effizienz des gesamten Verfahrens - Abscheidung, Transport und Speicherung - beträgt etwa 90%. Das heisst, für jede Tonne CO2, die gespeichert wird, entstehen 100kg CO2-Emissionen. Somit werden 900 kg CO2-Emissionen schlussendlich langfristig vermieden. Wie hoch ist die totale Speicherkapazität, und wie viel CO2 soll mit dem Verfahren gespeichert werden? Gemäss der langfristigen Klimastrategie der Schweiz belaufen sich die verbleibenden, schwer vermeidbaren Treibhausgasemissionen aus Industrie, Abfallwirtschaft und Landwirtschaft auf rund 12 Millionen Tonnen CO2 pro Jahr. Im Jahr 2050 beträgt das Speicherpotenzial von CO2 in Abbruchbeton rund 500'000 Tonnen CO2 in der Schweiz. Wie hoch sind die Kosten pro Tonne gespeichertes CO2 im gesamten Verfahren, also von der Abscheidung bis zur Speicherung? Die Kosten für eine flächendeckende Einführung dieser Technologie dürften bei einigen hundert Franken pro Tonne gespeichertem CO2 liegen. Durch eine breite Anwendung der Technologie kann der Prozess optimiert und die Kosten gesenkt werden. Wird dieses Verfahren bereits in anderen Projekten angewendet? Momentan betreibt die Firma Neustark in der Schweiz das Verfahren, wobei abgeschiedenes CO2 im Beton gebunden wird. Weitere Unternehmen, die ähnliche Prozesse entwickeln, sind Zirkulit und Sika.	In dem nachfolgenden Q&A erhalten Sie weitere Informationen zu diesem Verfahren. Bitte lesen Sie das Q&A zuerst in Ruhe durch, bevor Sie die weiteren Fragen beantworten. Was ist die gesamte CO2-Bilanz des Verfahrens? Jeder Schritt des Verfahrens braucht zusätzlich Material und Energie. Die CO2-Effizienz des gesamten Verfahrens - Abscheidung, Transport und Speicherung - beträgt etwa 75-80%. Das bedeutet, für jede Tonne CO2, die gespeichert wird, entstehen zwischen 200-250 kg CO2-Emissionen. Somit werden 750-800 kg CO2-Emissionen schlussendlich langfristig vermieden. Wie hoch ist die totale Speicherkapazität, und wie viel CO2 soll mit dem Verfahren gespeichert werden? Gemäss der langfristigen Klimastrategie der Schweiz belaufen sich die verbleibenden, schwer vermeidbaren Treibhausgasemissionen aus Industrie, Abfallwirtschaft und Landwirtschaft auf rund 12 Millionen Tonnen CO2 pro Jahr. Die theoretische Speicherkapazität (durch Mineralisierung) im Meeresboden liegt in der Größenordnung von 100'000-250'000 Milliarden Tonnen CO2. Wie hoch sind die Kosten pro Tonne gespeichertes CO2 im gesamten Verfahren, also von der Abscheidung bis zur Speicherung? Die Kosten für eine breite Anwendung dieser Technologie dürften bei mehreren hundert Franken pro Tonne gespeichertem CO2 liegen. Durch die breite Anwendung der Technologie kann der Prozess optimiert und die Kosten erheblich gesenkt werden. Wird dieses Verfahren bereits in anderen Projekten angewendet? Das Projekt von Sleipner in Norwegen hat bereits 1996 begonnen, CO2 in den Untergrund zu pumpen und dort zu speichern. Jährlich speichert Sleipner rund 1 Million Tonnen CO2 etwa 1 km unter dem Meeresboden. Ein weiteres Projekt ist Greensand, welches CO2 in Belgien aus der Industrie abscheidet, anschliessend nach Dänemark transportiert und dort im Untergrund speichert.



CO2 Abscheidung und Speicherung

Công Ly • Sie
1 Woche • Bearbeitet •

Das Interesse an [#CCTS](#) in der Bevölkerung ist gross. Daher möchten wir Ihnen hier einige wichtige Fragen zum [#DemoUpCARMA](#) Projekt beantworten:

■ WAS IST DIE GESAMTE CO2-BILANZ DES VERFAHRENS?

Jeder Schritt des Verfahrens braucht zusätzlich Material und Energie. Die CO2-Effizienz des gesamten Verfahrens - Abscheidung, Transport und Speicherung - beträgt etwa 90%. Das heißt, für jede Tonne CO2, die gespeichert wird, entstehen 100kg CO2-Emissionen. Somit werden 900 kg CO2-Emissionen schlussendlich langfristig vermieden.

■ WIE HOCH IST DIE TOTALE SPEICHERKAPAZITÄT, UND WIE VIEL CO2 SOLL MIT DEM VERFAHREN GESPEICHERT WERDEN?

Gemäss der langfristigen [#netzero](#) Klimastrategie der Schweiz belaufen sich die verbleibenden, schwer vermeidbaren Treibhausgasemissionen aus Industrie, Abfallwirtschaft und Landwirtschaft auf rund 12 Millionen Tonnen CO2 pro Jahr. Im Jahr 2050 beträgt das Speicherpotenzial von CO2 in Abbruchbeton rund 500'000 Tonnen CO2 in der Schweiz.

■ WIE HOCH SIND DIE KOSTEN PRO TONNE GESPEICHERTES CO2 IM GESAMTEN VERFAHREN, ALSO VON DER ABSCHIEDUNG BIS ZUR SPEICHERUNG?

Die Kosten für eine flächendeckende Einführung dieser Technologie dürften bei einigen hundert Franken pro Tonne gespeichertem CO2 liegen. Durch eine breite Anwendung der Technologie kann der Prozess optimiert und die Kosten gesenkt werden.

■ WIRD DIESES VERFAHREN BEREITS IN ANDEREN PROJEKTEN ANGEWENDET?

Momentan betreibt die Firma Neustark in der Schweiz das Verfahren, wobei abgeschiedenes CO2 im Beton gebunden wird. Weitere Unternehmen, die ähnliche Prozesse entwickeln, sind Zirkulit und Sika.

Haben Sie noch weitere Fragen zu [#CCTS](#), die sie gerne beantwortet haben möchten?



Gefällt mir



Kommentar



CO2 Abscheidung und Speicherung

Công Ly • Sie
1 Woche • Bearbeitet •

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Gemäss der langfristigen [#netzero](#) Klimastrategie der Schweiz, belaufen sich die verbleibenden, schwer vermeidbaren Treibhausgasemissionen aus Industrie, Abfallwirtschaft und Landwirtschaft auf rund 12 Millionen Tonnen CO2 pro Jahr. Die theoretische Speicherkapazität (durch Mineralisierung) im Meeresboden liegt in der Größenordnung von 100'000-250'000 Milliarden Tonnen CO2.

■ WIE HOCH SIND DIE KOSTEN PRO TONNE GESPEICHERTES CO2 IM GESAMTEN VERFAHREN, ALSO VON DER ABSCHIEDUNG BIS ZUR SPEICHERUNG?

Die Kosten für eine breite Anwendung dieser Technologie dürften bei einigen hundert Franken pro Tonne gespeichertem CO2 liegen. Durch die breite Anwendung der Technologie kann der Prozess optimiert und die Kosten gesenkt werden.

■ WIRD DIESES VERFAHREN BEREITS IN ANDEREN PROJEKTEN ANGEWENDET?

Das Projekt von Sleipner in Norwegen hat bereits 1996 begonnen, CO2 in den Untergrund zu pumpen und dort zu speichern. Jährlich speichert Sleipner rund 1 Million Tonnen CO2 etwa 1 km unter dem Meeresboden. Ein weiteres Projekt ist Greensand, welches CO2 in Belgien aus der Industrie abscheidet, anschliessend nach Dänemark transportiert und dort im Untergrund speichert.

Haben Sie noch weitere Fragen zu [#CCTS](#), die sie gerne beantwortet haben möchten?



Gefällt mir



Kommentar

B-2: Entire questionnaire [German version]

In the following the entire questionnaire is listed with the different arms in question block 3:

Startseite

Herzlich willkommen

Vielen Dank für Ihre Teilnahme an dieser Umfrage, welche von der ETH Zürich im Rahmen des Forschungsprojektes DemoUpCARMA durchgeführt wird. DemoUpCARMA ist ein von der ETH Zürich geleitetes und vom Bundesamt für Energie und vom Bundesamt für Umwelt finanziertes und unterstütztes Pilotprojekt. DemoUpCARMA zeigt zwei Verfahren zur Reduktion von CO2 Emissionen auf. Für diese zwei Verfahren werden technologische, wirtschaftliche, regulatorische sowie gesellschaftliche Aspekte untersucht. In dieser Umfrage können Sie Ihre Meinung und Gedanken zu einem dieser beiden Verfahren äussern, welche ins Projekt einfließen werden. Werte und Zahlen, die in der Umfrage kommuniziert werden, sind lediglich Annäherungen.

Zustimmungserklärung

Wie erheben und verarbeiten wir Ihre Daten?

Das Ausfüllen der Umfrage dauert etwa 15-20 Minuten. Die Daten werden in anonymer Form erhoben und gemäss den Bestimmungen des [Bundesgesetzes über den Datenschutz](#) behandelt. Ihre Angaben können somit nicht mit Ihrer Person in Verbindung gebracht werden und werden nicht an Dritte weitergegeben. Die Teilnahme ist freiwillig und Sie können die Umfrage jederzeit abbrechen. Falls Sie Fragen haben, wenden Sie sich bitte an Dr. Irina Dallo: irina.dallo@sed.ethz.ch.

Bitte beachten Sie, dass Sie während der Umfrage nicht auf die vorherige Seite zurückkehren können.

- Ich stimme zu, dass meine personenbezogenen Daten gemäss den hier aufgeführten Angaben verarbeitet werden.

Quoten

Geschlecht

- Weiblich
- Männlich
- Divers

Wie alt sind Sie (in Jahren)? [Textfeld]

Question block 1

Hintergrund zum Verfahren

Die Schweiz hat sich zum Ziel gesetzt, ihre Treibhausgasemissionen bis 2050 auf Netto-Null zu reduzieren. Netto-Null bedeutet, dass nur so viele Treibhausgase ausgestossen werden, wie sich durch natürliche oder technische Massnahmen der Atmosphäre wieder entziehen lassen. Dies ist nötig, um die nationalen Klimaziele zu erreichen. Das Verfahren, welches Sie auf der nächsten Seite kennen lernen werden, hat zum Ziel, schwer vermeidbare Treibhausgasemissionen der Atmosphäre zu entziehen, welche beispielsweise beim Verbrennen von Abfall oder in der Landwirtschaft entstehen. Solche Verfahren nennt man CO₂ Abscheidungs- und Speicherungstechnologien (Carbon Capture, Transport and Storage (CCTS)).

Wie schätzen Sie Ihr Wissen über CO₂ Abscheidungs- und Speicherungstechnologien ein?

- Ich weiss nichts darüber.
- Ich weiss sehr wenig darüber.
- Ich weiss ein wenig darüber.
- Ich weiss einiges darüber.
- Ich weiss viel darüber.

Würden Sie im Allgemeinen CO₂ Abscheidungs- und Speicherungstechnologien unterstützen?

- Lehne ich strikt ab.
- Lehne ich ab.
- Ich bin neutral
- Unterstütze ich.
- Unterstütze ich voll und ganz.
- Kann ich nicht sagen, da ich zu wenig weiss.

Aufmerksamkeitsfrage

Um sicher zu gehen, dass Sie die Fragen aufmerksam lesen, kreuzen Sie bitte "Ich stimme überhaupt nicht zu" an.

- Ich stimme überhaupt nicht zu.
- Ich stimme nicht zu
- Weder noch.
- Ich stimme zu.
- Ich stimme voll und ganz zu.

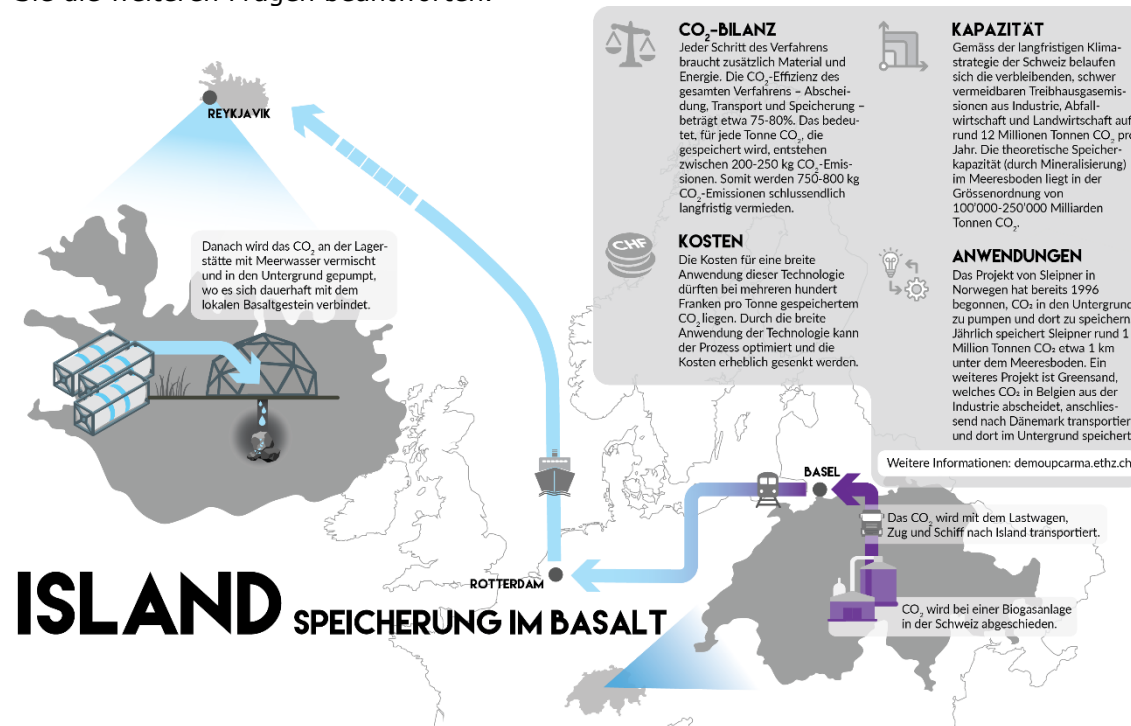
- ☐ Vielen Dank für Ihr Interesse diese Umfrage auszufüllen. Jedoch haben Sie die Aufmerksamkeitsfrage nicht richtig beantwortet und werden nun zum Ende der Umfrage geleitet.

Question block I1

In einem nächsten Schritt lernen Sie nun ein Verfahren zur CO₂-Abscheidung und -Speicherung kennen.

CO₂ wird bei einer Biogasanlage in der Schweiz abgeschieden, indem das CO₂ nach der Produktion von Biogas separiert wird. Das CO₂ wird anschliessend mit dem Lastwagen, Zug und Schiff nach Island transportiert. Danach wird das CO₂ an der Lagerstätte mit Meerwasser vermischt und in den Untergrund gepumpt, wo es sich dauerhaft mit dem lokalen Basaltgestein verbindet (=Mineralisierung). Dieses Verfahren entzieht somit CO₂ dauerhaft der Atmosphäre und trägt zum Erreichen der nationalen Klimaziele bei.

In der nachfolgenden Infografik finden Sie weitere Informationen zu diesem Verfahren. Bitte schauen Sie sich die Infografik zuerst in Ruhe an, bevor Sie die weiteren Fragen beantworten.



Was ist Ihr erster Eindruck von diesem Verfahren?

[Textfeld]

Wie schätzen Sie Ihr Wissen über dieses Verfahren ein?

- Ich weiss nichts darüber.
- Ich weiss sehr wenig darüber.
- Ich weiss ein wenig darüber.
- Ich weiss einiges darüber.
- Ich weiss viel darüber.

Bitte beurteilen Sie ausgehend von der Infografik, ob folgende Aussagen korrekt sind oder nicht.

[Bitte kreuzen Sie alle korrekten Aussagen an.]

- Die Kosten können durch eine breite Anwendung der Technologie gesenkt werden.
- Es handelt sich um ein Verfahren, das noch nie vorher angewandt wurde.
- Durch dieses Verfahren können alle schwer vermeidbaren CO₂-Emissionen in der Schweiz abgeschieden und gespeichert werden.
- Das Verfahren ermöglicht es, schwer vermeidbare CO₂-Emissionen auszugleichen, auch unter Berücksichtigung der Emissionen während der Abscheidung, des Transports und der Speicherung.

Die Infografik ist:

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Informativ
- Verständlich
- Strukturiert
- Übersichtlich
- Ansprechend gestaltet
- Vertrauenswürdig

Wie stark stimmen Sie den folgenden Aussagen zu?

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Das Verfahren ist nützlich.
- Das Verfahren ist akzeptabel.
- Das Verfahren ist nötig, um die schwer zu vermeidenden CO₂-Emissionen auszugleichen.

- Das Verfahren ist nötig, um die Klimaziele der Schweiz zu erreichen.
- Das Verfahren muss von der isländischen Bevölkerung befürwortet werden.
- Das Verfahren ist sicher.
- Das Verfahren ist sinnvoll.

Inwieweit unterstützen Sie dieses Verfahren?

- Lehne ich strikt ab.
- Lehne ich ab.
- Ich bin neutral
- Unterstütze ich.
- Unterstütze ich voll und ganz.
- Kann ich nicht sagen, da ich zu wenig weiss.

Wie stark stimmen Sie den folgenden Aussagen zu?

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Der Ausbau dieses Verfahrens führt zu neuen Arbeitsplätzen.
- Die Industrie beteiligt sich an den Massnahmen zur Reduktion der CO₂-Emissionen und übernimmt damit Verantwortung für die von ihr verursachten Emissionen.
- Dieses Verfahren fördert das Umweltbewusstsein in der Gesellschaft.
- Das Verfahren erhöht die Chance, die Klimaziele der Schweiz zu erreichen.
- CO₂ könnte aus der Gesteinsformation an die Oberfläche entweichen.
- Die Schweiz exportiert ihre Probleme nach Island.
- Die geopolitischen Abhängigkeiten könnten zum Scheitern des Projektes führen.
- Die CO₂ Speicherung im Untergrund hat negative Effekte auf das Ökosystem im Untergrund (z. B., Trinkwasserverschmutzung, Lebewesen, Biodiversität).
- Grössere Naturereignisse wie Erdbeben oder Vulkanausbrüche können zum Entweichen des CO₂ führen.
- CO₂ kann während des Transports entweichen.
- Das Verfahren ist gesundheitsschädlich.
- Die Technologie erfordert keine Eingriffe in die Natur.

Was würden Sie noch gerne über das Verfahren wissen?

[Textfeld]

Momentan wird auch geprüft, ob CO₂ bei uns in der Schweiz in geeigneten geologischen Formationen gespeichert werden könnte.

Wie stark stimmen Sie den folgenden Aussagen zu?

- Ich würde den Bau einer Speicheranlage in meiner Nachbarschaft akzeptieren.
- Ich denke, eine Speicheranlage in meiner Nachbarschaft würde keine Probleme bereiten.
- Ich wäre besorgt, wenn eine Speicheranlage in meiner Nachbarschaft gebaut würde.
- Ich würde gegen den Bau einer Speicheranlage in meiner Nachbarschaft protestieren.

Question block I2

In einem nächsten Schritt lernen Sie nun ein Verfahren zur CO₂-Abscheidung und -Speicherung kennen.

CO₂ wird bei einer Biogasanlage in der Schweiz abgeschieden, indem das CO₂ nach der Produktion vom Biogas separiert wird. Das CO₂ wird anschliessend mit dem Lastwagen, Zug und Schiff nach Island transportiert. Danach wird das CO₂ an der Lagerstätte mit Meerwasser vermischt und in den Untergrund gepumpt, wo es sich dauerhaft mit dem lokalen Basaltgestein verbindet (=Mineralisierung). Dieses Verfahren entzieht somit CO₂ dauerhaft der Atmosphäre und trägt zum Erreichen der nationalen Klimaziele bei.

In dem nachfolgenden Q&A erhalten Sie weitere Informationen zu diesem Verfahren. Bitte lesen Sie das Q&A zuerst in Ruhe durch, bevor Sie die weiteren Fragen beantworten.

Was ist die gesamte CO₂-Bilanz des Verfahrens?

Jeder Schritt des Verfahrens braucht zusätzlich Material und Energie. Die CO₂-Effizienz des gesamten Verfahrens - Abscheidung, Transport und Speicherung - beträgt etwa 75-80%. Das bedeutet, für jede Tonne CO₂, die gespeichert wird, entstehen zwischen 200-250 kg CO₂-Emissionen. Somit werden 750-800 kg CO₂-Emissionen schlussendlich langfristig vermieden.

Wie hoch ist die totale Speicherkapazität, und wie viel CO₂ soll mit dem Verfahren gespeichert werden?

Gemäss der langfristigen Klimastrategie der Schweiz belaufen sich die verbleibenden, schwer vermeidbaren Treibhausgasemissionen aus Industrie, Abfallwirtschaft und Landwirtschaft auf rund 12 Millionen Tonnen CO₂ pro Jahr. Die theoretische Speicherkapazität (durch Mineralisierung) im Meeresboden liegt in der Größenordnung von 100'000-250'000 Milliarden Tonnen CO₂.

Wie hoch sind die Kosten pro Tonne gespeichertes CO₂ im gesamten Verfahren, also von der Abscheidung bis zur Speicherung?

Die Kosten für eine breite Anwendung dieser Technologie dürften bei mehreren hundert Franken pro Tonne gespeichertem CO₂ liegen. Durch die breite Anwendung der Technologie kann der Prozess optimiert und die Kosten erheblich gesenkt werden.

Wird dieses Verfahren bereits in anderen Projekten angewendet?

Das Projekt von Sleipner in Norwegen hat bereits 1996 begonnen, CO₂ in den Untergrund zu pumpen und dort zu speichern. Jährlich speichert Sleipner rund 1 Million Tonnen CO₂ etwa 1 km unter dem Meeresboden. Ein weiteres Projekt ist Greensand, welches CO₂ in Belgien aus der Industrie abscheidet, anschliessend nach Dänemark transportiert und dort im Untergrund speichert.

Was ist Ihr erster Eindruck von diesem Verfahren?

[Textfeld]

Wie schätzen Sie Ihr Wissen über dieses Verfahren ein?

- Ich weiss nichts darüber.
- Ich weiss sehr wenig darüber.
- Ich weiss ein wenig darüber.
- Ich weiss einiges darüber.
- Ich weiss viel darüber.

Bitte beurteilen Sie ausgehend von dem Q&A, ob folgende Aussagen korrekt sind oder nicht.

[Bitte kreuzen Sie alle korrekten Aussagen an.]

- Die Kosten können durch eine breite Anwendung der Technologie gesenkt werden.
- Es handelt sich um ein Verfahren, das noch nie vorher angewandt wurde.
- Durch dieses Verfahren können alle schwer vermeidbaren CO₂-Emissionen in der Schweiz abgeschieden und gespeichert werden.
- Das Verfahren ermöglicht es, schwer vermeidbare CO₂-Emissionen auszugleichen, auch unter Berücksichtigung der Emissionen während der Abscheidung, des Transports und der Speicherung.

Das Q&A ist:

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Informativ
- Verständlich
- Strukturiert
- Übersichtlich
- Ansprechend gestaltet
- Vertrauenswürdig

Wie stark stimmen Sie den folgenden Aussagen zu?

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Das Verfahren ist nützlich.
- Das Verfahren ist akzeptabel.
- Das Verfahren ist nötig, um die schwer zu vermeidenden CO₂-Emissionen auszugleichen.
- Das Verfahren ist nötig, um die Klimaziele der Schweiz zu erreichen.
- Das Verfahren muss von der isländischen Bevölkerung befürwortet werden.
- Das Verfahren ist sicher.
- Das Verfahren ist sinnvoll.

Inwieweit unterstützen Sie dieses Verfahren?

- Lehne ich strikt ab.
- Lehne ich ab.
- Ich bin neutral
- Unterstütze ich.
- Unterstütze ich voll und ganz.
- Kann ich nicht sagen, da ich zu wenig weiss.

Wie stark stimmen Sie den folgenden Aussagen zu?

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Der Ausbau dieses Verfahrens führt zu neuen Arbeitsplätzen.
- Die Industrie beteiligt sich an den Massnahmen zur Reduktion der CO₂-Emissionen und übernimmt damit Verantwortung für die von ihr verursachten Emissionen.
- Dieses Verfahren fördert das Umweltbewusstsein in der Gesellschaft.
- Das Verfahren erhöht die Chance, die Klimaziele der Schweiz zu erreichen.
- CO₂ könnte aus der Gesteinsformation an die Oberfläche entweichen.
- Die Schweiz exportiert ihre Probleme nach Island.
- Die geopolitischen Abhängigkeiten könnten zum Scheitern des Projektes führen.
- Die CO₂ Speicherung im Untergrund hat negative Effekte auf das Ökosystem im Untergrund (z. B., Trinkwasserverschmutzung, Lebewesen, Biodiversität).
- Grössere Naturereignisse wie Erdbeben oder Vulkanausbrüche können zum Entweichen des CO₂ führen.

- CO2 kann während des Transports entweichen.
- Das Verfahren ist gesundheitsschädlich.
- Die Technologie erfordert keine Eingriffe in die Natur.

Was würden Sie noch gerne über das Verfahren wissen?

[Textfeld]

Momentan wird auch geprüft, ob CO2 bei uns in der Schweiz in geeigneten geologischen Formationen gespeichert werden könnte.

Wie stark stimmen Sie den folgenden Aussagen zu?

- Ich würde den Bau einer Speicheranlage in meiner Nachbarschaft akzeptieren.
- Ich denke, eine Speicheranlage in meiner Nachbarschaft würde keine Probleme bereiten.
- Ich wäre besorgt, wenn eine Speicheranlage in meiner Nachbarschaft gebaut würde.
- Ich würde gegen den Bau einer Speicheranlage in meiner Nachbarschaft protestieren.

Question block I3

In einem nächsten Schritt lernen Sie nun ein Verfahren zur CO2-Abscheidung und -Speicherung kennen.

CO2 wird bei einer Biogasanlage in der Schweiz abgeschieden (CO2 wird nach der Produktion vom Biogas separiert) und mit dem Lastwagen, Zug und Schiff nach Island transportiert. Danach wird das CO2 an der Lagerstätte mit Meerwasser vermischt und in den Untergrund gepumpt, wo es sich dauerhaft mit dem lokalen Basaltgestein verbindet (=Mineralisierung). Dieses Verfahren entzieht CO2 dauerhaft der Atmosphäre und trägt somit zum Erreichen der nationalen Klimaziele bei.

In dem nachfolgenden Q&A auf LinkedIn erhalten Sie weitere Informationen zu diesem Verfahren. Bitte lesen Sie das Q&A zuerst in Ruhe durch, bevor Sie die weiteren Fragen beantworten.



CO2 Abscheidung und Speicherung

Công Ly • Sie

1 Woche • Bearbeitet •

...

Das Interesse an [#CCTS](#) in der Bevölkerung ist gross. Daher möchten wir Ihnen hier einige wichtige Fragen zum [#DemoUpCARMA](#) Projekt beantworten:

■ WAS IST DIE GESAMTE CO2-BILANZ DES VERFAHRENS?

Jeder Schritt des Verfahrens braucht zusätzlich Material und Energie. Die CO2-Effizienz des gesamten Verfahrens - Abscheidung, Transport und Speicherung - beträgt etwa 75-80%. Das bedeutet, für jede Tonne CO2, die gespeichert wird, entstehen zwischen 200-250 kg CO2-Emissionen. Somit werden 750-800 kg CO2-Emissionen schlussendlich langfristig vermieden.

■ WIE HOCH IST DIE TOTALE SPEICHERKAPAZITÄT, UND WIE VIEL CO2 SOLL MIT DEM VERFAHREN GESPEICHERT WERDEN?

Gemäss der langfristigen [#netzero](#) Klimastrategie der Schweiz, belaufen sich die verbleibenden, schwer vermeidbaren Treibhausgasemissionen aus Industrie, Abfallwirtschaft und Landwirtschaft auf rund 12 Millionen Tonnen CO2 pro Jahr. Die theoretische Speicherkapazität (durch Mineralisierung) im Meeresboden liegt in der Größenordnung von 100'000-250'000 Milliarden Tonnen CO2.

■ WIE HOCH SIND DIE KOSTEN PRO TONNE GESPEICHERTES CO2 IM GESAMTEN VERFAHREN, ALSO VON DER ABSCHIEDUNG BIS ZUR SPEICHERUNG?

Die Kosten für eine breite Anwendung dieser Technologie dürften bei einigen hundert Franken pro Tonne gespeichertem CO2 liegen. Durch die breite Anwendung der Technologie kann der Prozess optimiert und die Kosten gesenkt werden.

■ WIRD DIESES VERFAHREN BEREITS IN ANDEREN PROJEKTEN ANGEWENDET?

Das Projekt von Sleipner in Norwegen hat bereits 1996 begonnen, CO2 in den Untergrund zu pumpen und dort zu speichern. Jährlich speichert Sleipner rund 1 Million Tonnen CO2 etwa 1 km unter dem Meeresboden. Ein weiteres Projekt ist Greensand, welches CO2 in Belgien aus der Industrie abscheidet, anschliessend nach Dänemark transportiert und dort im Untergrund speichert.

Haben Sie noch weitere Fragen zu [#CCTS](#), die sie gerne beantwortet haben möchten?



Gefällt mir



Kommentar

Was ist Ihr erster Eindruck von diesem Verfahren?

[Textfeld]

Wie schätzen Sie Ihr Wissen über dieses Verfahren ein?

- ☐ Ich weiss nichts darüber.
- ☐ Ich weiss sehr wenig darüber.
- ☐ Ich weiss ein wenig darüber.
- ☐ Ich weiss einiges darüber.
- ☐ Ich weiss viel darüber.

Bitte beurteilen Sie ausgehend von dem Q&A, ob folgende Aussagen korrekt sind oder nicht.

[Bitte kreuzen Sie alle korrekten Aussagen an.]

- ☐ Die Kosten können durch eine breite Anwendung der Technologie gesenkt werden.
- ☐ Es handelt sich um ein Verfahren, das noch nie vorher angewandt wurde.
- ☐ Durch dieses Verfahren können alle schwer vermeidbaren CO₂-Emissionen in der Schweiz abgeschieden und gespeichert werden.
- ☐ Das Verfahren ermöglicht es, schwer vermeidbare CO₂-Emissionen auszugleichen, auch unter Berücksichtigung der Emissionen während der Abscheidung, des Transports und der Speicherung.

Das Q&A ist:

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- ☐ Informativ
- ☐ Verständlich
- ☐ Strukturiert
- ☐ Übersichtlich
- ☐ Ansprechend gestaltet
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Wie stark stimmen Sie den folgenden Aussagen zu?

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- Das Verfahren ist nötig, um die Klimaziele der Schweiz zu erreichen.
- Das Verfahren muss von der isländischen Bevölkerung befürwortet werden.
- Das Verfahren ist sicher.
- Das Verfahren ist sinnvoll.

Inwieweit unterstützen Sie dieses Verfahren?

- Lehne ich strikt ab.
- Lehne ich ab.
- Ich bin neutral
- Unterstütze ich.
- Unterstütze ich voll und ganz.
- Kann ich nicht sagen, da ich zu wenig weiss.

Wie stark stimmen Sie den folgenden Aussagen zu?

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- Der Ausbau dieses Verfahrens führt zu neuen Arbeitsplätzen.
- Die Industrie beteiligt sich an den Massnahmen zur Reduktion der CO₂-Emissionen und übernimmt damit Verantwortung für die von ihr verursachten Emissionen.
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Was würden Sie noch gerne über das Verfahren wissen?

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- Ich würde den Bau einer Speicheranlage in meiner Nachbarschaft akzeptieren.
- Ich denke, eine Speicheranlage in meiner Nachbarschaft würde keine Probleme bereiten.
- Ich wäre besorgt, wenn eine Speicheranlage in meiner Nachbarschaft gebaut würde.
- Ich würde gegen den Bau einer Speicheranlage in meiner Nachbarschaft protestieren.

Question block 14

In einem nächsten Schritt lernen Sie nun ein Verfahren zur CO₂-Abscheidung und -Speicherung kennen.

CO₂ wird bei einer Biogasanlage in der Schweiz abgeschieden (CO₂ wird nach der Produktion vom Biogas separiert) und mit dem Lastwagen, Zug und Schiff nach Island transportiert. Danach wird das CO₂ an der Lagerstätte mit Meerwasser vermischt und in den Untergrund gepumpt, wo es sich dauerhaft mit dem lokalen Basaltgestein verbindet (=Mineralisierung). Dieses Verfahren entzieht CO₂ dauerhaft der Atmosphäre und trägt somit zum Erreichen der nationalen Klimaziele bei.

Im nachfolgendem Text erhalten Sie weitere Informationen zu diesem Verfahren. Bitte lesen Sie den Text zuerst in Ruhe durch, bevor Sie die weiteren Fragen beantworten.

Gemäss der langfristigen Klimastrategie der Schweiz belaufen sich die verbleibenden, schwer vermeidbaren Treibhausgasemissionen aus Industrie, Abfallwirtschaft und Landwirtschaft auf rund 12 Millionen Tonnen CO₂ pro Jahr. Die theoretische Speicherkapazität durch Mineralisierung im Meeresboden liegt in der Größenordnung von 100'000-250'000 Milliarden Tonnen CO₂. Die Kosten für eine breite Anwendung dieser Technologie dürften bei einigen hundert Franken pro Tonne gespeichertem CO₂ liegen. Durch die breite Anwendung der Technologie kann aber der Prozess optimiert und die Kosten gesenkt werden. Die CO₂-Effizienz des gesamten Verfahrens - Abscheidung, Transport und Speicherung - beträgt etwa 75-80%. Das bedeutet, für jede Tonne CO₂, die gespeichert wird, entstehen zwischen 200-250 kg CO₂-Emissionen. Somit werden 750-800 kg CO₂-Emissionen schlussendlich langfristig vermieden. Ähnliche Verfahren werden bereits in anderen Projekten angewendet. Sleipner in Norwegen hat 1996 begonnen, CO₂ in den Untergrund zu pumpen und dort zu speichern. Jährlich speichert Sleipner rund 1 Million Tonnen CO₂ etwa 1 km unter dem Meeresboden. Ein weiteres Projekt ist Greensand, welches CO₂ in Belgien aus der Industrie abscheidet, nach Dänemark transportiert und dort im Untergrund speichert.

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- Das Verfahren ist sicher.

- Das Verfahren ist sinnvoll.

Inwieweit unterstützen Sie dieses Verfahren?

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[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Der Ausbau dieses Verfahrens führt zu neuen Arbeitsplätzen.
- Die Industrie beteiligt sich an den Massnahmen zur Reduktion der CO₂-Emissionen und übernimmt damit Verantwortung für die von ihr verursachten Emissionen.
- Dieses Verfahren fördert das Umweltbewusstsein in der Gesellschaft.
- Das Verfahren erhöht die Chance, die Klimaziele der Schweiz zu erreichen.
- CO₂ könnte aus der Gesteinsformation an die Oberfläche entweichen.
- Die Schweiz exportiert ihre Probleme nach Island.
- Die geopolitischen Abhängigkeiten könnten zum Scheitern des Projektes führen.
- Die CO₂ Speicherung im Untergrund hat negative Effekte auf das Ökosystem im Untergrund (z. B., Trinkwasserverschmutzung, Lebewesen, Biodiversität).
- Grössere Naturereignisse wie Erdbeben oder Vulkanausbrüche können zum Entweichen des CO₂ führen.
- CO₂ kann während des Transports entweichen.
- Das Verfahren ist gesundheitsschädlich.
- Die Technologie erfordert keine Eingriffe in die Natur.

Was würden Sie noch gerne über das Verfahren wissen?

[Textfeld]

Momentan wird auch geprüft, ob CO₂ bei uns in der Schweiz in geeigneten geologischen Formationen gespeichert werden könnte.

Wie stark stimmen Sie den folgenden Aussagen zu?

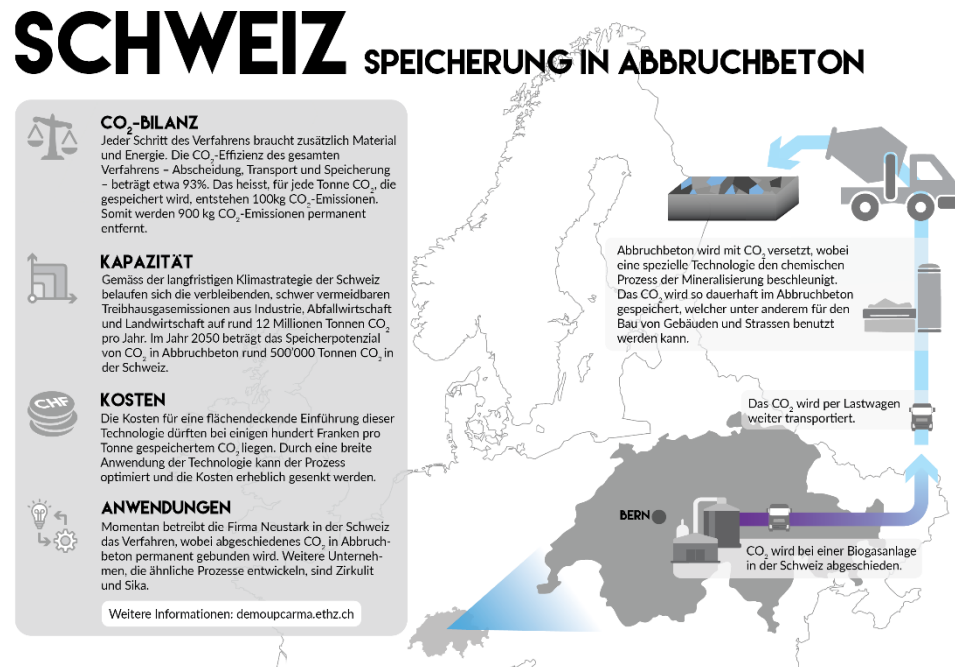
- Ich würde den Bau einer Speicheranlage in meiner Nachbarschaft akzeptieren.
- Ich denke, eine Speicheranlage in meiner Nachbarschaft würde keine Probleme bereiten.
- Ich wäre besorgt, wenn eine Speicheranlage in meiner Nachbarschaft gebaut würde.
- Ich würde gegen den Bau einer Speicheranlage in meiner Nachbarschaft protestieren.

Question block S1

In einem nächsten Schritt lernen Sie nun ein Verfahren zur CO₂-Abscheidung und -Speicherung kennen.

CO₂ wird in einer Biogasanlage in der Schweiz abgeschieden (CO₂ wird nach der Produktion von Biogas separiert). Das CO₂ wird per Lastwagen weiter transportiert und dann durch ein technisches Verfahren dauerhaft in Abbruchbeton gebunden (Mineralisierung). Der Beton kann unter anderem für den Bau von Gebäuden oder Strassen benutzt werden. Alle diese Prozessschritte finden in der Schweiz statt. Dieses Verfahren entzieht CO₂ somit dauerhaft der Atmosphäre und trägt zum Erreichen der nationalen Klimaziele bei.

In der folgenden Infografik erhalten Sie weitere Informationen zu diesem Verfahren. Bitte schauen Sie sich die Infografik zuerst in Ruhe an, bevor Sie die weiteren Fragen beantworten.



Was ist Ihr erster Eindruck von diesem Verfahren?

[Textfeld]

Wie schätzen Sie Ihr Wissen über dieses Verfahren ein?

- Ich weiss nichts darüber.
- Ich weiss sehr wenig darüber.
- Ich weiss ein wenig darüber.
- Ich weiss einiges darüber.
- Ich weiss viel darüber.

Bitte beurteilen Sie ausgehend von der Infografik, ob folgende Aussagen korrekt sind oder nicht.

[Bitte kreuzen Sie alle korrekten Aussagen an.]

- Die Kosten können durch eine breite Anwendung der Technologie gesenkt werden.
- Es handelt sich um ein Verfahren, das noch nie vorher angewandt wurde.
- Durch dieses Verfahren können alle schwer vermeidbaren CO₂-Emissionen in der Schweiz abgeschieden und gespeichert werden.
- Das Verfahren ermöglicht es, schwer vermeidbare CO₂-Emissionen auszugleichen, auch unter Berücksichtigung der Emissionen während der Abscheidung, des Transports und der Speicherung.

Die Infografik ist:

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Informativ
- Verständlich
- Strukturiert
- Übersichtlich
- Ansprechend gestaltet
- Vertrauenswürdig

Wie stark stimmen Sie den folgenden Aussagen zu?

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Das Verfahren ist nützlich.

- Das Verfahren ist akzeptabel.
- Das Verfahren ist nötig, um die schwer zu vermeidenden CO₂-Emissionen auszugleichen.
- Das Verfahren ist nötig, um die Klimaziele der Schweiz zu erreichen.
- Das Verfahren muss von der schweizer Bevölkerung befürwortet werden.
- Das Verfahren ist sicher.
- Das Verfahren ist sinnvoll.

Inwieweit unterstützen Sie dieses Verfahren?

- Lehne ich strikt ab.
- Lehne ich ab.
- Ich bin neutral
- Unterstütze ich.
- Unterstütze ich voll und ganz.
- Kann ich nicht sagen, da ich zu wenig weiss.

Wie stark stimmen Sie den folgenden Aussagen zu dem Verfahren zu?

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Es ist gut, dass es eine lokale Lösung zur Reduktion von CO₂-Emissionen ist.
- Die Technologie erfordert keine Eingriffe in die Natur.
- Die Technologie hat ein geringes Risiko, dass CO₂ entweichen kann.
- Der Ausbau der Technologie führt zu neuen Arbeitsplätzen.
- Die Industrie beteiligt sich an den Massnahmen zur Reduktion der CO₂-Emissionen und übernimmt damit Verantwortung für die von ihr verursachten Emissionen.
- Die Technologie fördert das Umweltbewusstsein in der Gesellschaft.
- Das Verfahren erhöht die Chance, die Klimaziele der Schweiz zu erreichen.
- Die Speicherung ist nicht für immer (z. B. Abriss von Gebäuden).
- Das Verfahren fördert den Gebrauch von Beton, anstatt auf andere nachhaltigere Baumaterialien auszuweichen.
- CO₂ könnte während des Transports entweichen.
- Das Verfahren ist gesundheitsschädlich.
- Die CO₂ Speicherung im Beton hat negative Effekte auf die Umwelt.

Was würden Sie noch gerne über das Verfahren wissen?

[Textfeld]

Question block S2

In einem nächsten Schritt lernen Sie nun ein Verfahren zur CO₂-Abscheidung und -Speicherung kennen.

CO₂ wird in einer Biogasanlage in der Schweiz abgeschieden (CO₂ wird nach der Produktion von Biogas separiert). Das CO₂ wird per Lastwagen weiter transportiert und dann durch ein technisches Verfahren dauerhaft in Abbruchbeton gebunden (Mineralisierung). Der Beton kann unter anderem für den Bau von Gebäuden oder Strassen benutzt werden. Alle diese Prozessschritte finden in der Schweiz statt. Dieses Verfahren entzieht CO₂ somit dauerhaft der Atmosphäre und trägt zum Erreichen der nationalen Klimaziele bei.

In dem folgenden Q&A erhalten Sie weitere Informationen zu diesem Verfahren. Bitte lesen Sie das Q&A zuerst in Ruhe durch, bevor Sie die weiteren Fragen beantworten.

Was ist die gesamte CO₂-Bilanz des Verfahrens?

Jeder Schritt des Verfahrens braucht zusätzlich Material und Energie. Die CO₂-Effizienz des gesamten Verfahrens - Abscheidung, Transport und Speicherung - beträgt etwa 90%. Das heißt, für jede Tonne CO₂, die gespeichert wird, entstehen 100kg CO₂-Emissionen. Somit werden 900 kg CO₂-Emissionen schlussendlich langfristig vermieden.

Wie hoch ist die totale Speicherkapazität, und wie viel CO₂ soll mit dem Verfahren gespeichert werden?

Gemäss der langfristigen Klimastrategie der Schweiz belaufen sich die verbleibenden, schwer vermeidbaren Treibhausgasemissionen aus Industrie, Abfallwirtschaft und Landwirtschaft auf rund 12 Millionen Tonnen CO₂ pro Jahr. Im Jahr 2050 beträgt das Speicherpotenzial von CO₂ in Abbruchbeton rund 500'000 Tonnen CO₂ in der Schweiz.

Wie hoch sind die Kosten pro Tonne gespeichertes CO₂ im gesamten Verfahren, also von der Abscheidung bis zur Speicherung?

Die Kosten für eine flächendeckende Einführung dieser Technologie dürften bei einigen hundert Franken pro Tonne gespeichertem CO₂ liegen. Durch eine breite Anwendung der Technologie kann der Prozess optimiert und die Kosten gesenkt werden.

Wird dieses Verfahren bereits in anderen Projekten angewendet?

Momentan betreibt die Firma Neustark in der Schweiz das Verfahren, wobei abgeschiedenes CO₂ im Beton gebunden wird. Weitere Unternehmen, die ähnliche Prozesse entwickeln, sind Zirkulit und Sika.

Was ist Ihr erster Eindruck von diesem Verfahren?

[Textfeld]

Wie schätzen Sie Ihr Wissen über dieses Verfahren ein?

- Ich weiss nichts darüber.

- Ich weiss sehr wenig darüber.
- Ich weiss ein wenig darüber.
- Ich weiss einiges darüber.
- Ich weiss viel darüber.

Bitte beurteilen Sie ausgehend vom Q&A, ob folgende Aussagen korrekt sind oder nicht.

[Bitte kreuzen Sie alle korrekten Aussagen an.]

- Die Kosten können durch eine breite Anwendung der Technologie gesenkt werden.
- Es handelt sich um ein Verfahren, das noch nie vorher angewandt wurde.
- Durch dieses Verfahren können alle schwer vermeidbaren CO₂-Emissionen in der Schweiz abgeschieden und gespeichert werden.
- Das Verfahren ermöglicht es, schwer vermeidbare CO₂-Emissionen auszugleichen, auch unter Berücksichtigung der Emissionen während der Abscheidung, des Transports und der Speicherung.

Das Q&A ist:

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Informativ
- Verständlich
- Strukturiert
- Übersichtlich
- Ansprechend gestaltet
- Vertrauenswürdig

Wie stark stimmen Sie den folgenden Aussagen zu?

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Das Verfahren ist nützlich.
- Das Verfahren ist akzeptabel.
- Das Verfahren ist nötig, um die schwer zu vermeidenden CO₂-Emissionen auszugleichen.
- Das Verfahren ist nötig, um die Klimaziele der Schweiz zu erreichen.
- Das Verfahren muss von der Schweizer Bevölkerung befürwortet werden.
- Das Verfahren ist sicher.

- Das Verfahren ist sinnvoll.

Inwieweit unterstützen Sie dieses Verfahren?

- Lehne ich strikt ab.
- Lehne ich ab.
- Ich bin neutral
- Unterstütze ich.
- Unterstütze ich voll und ganz.
- Kann ich nicht sagen, da ich zu wenig weiss.

Wie stark stimmen Sie den folgenden Aussagen zu dem Verfahren zu?

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Es ist gut, dass es eine lokale Lösung zur Reduktion von CO₂-Emissionen ist.
- Die Technologie erfordert keine Eingriffe in die Natur.
- Die Technologie hat ein geringes Risiko, dass CO₂ entweichen kann.
- Der Ausbau der Technologie führt zu neuen Arbeitsplätzen.
- Die Industrie beteiligt sich an den Massnahmen zur Reduktion der CO₂-Emissionen und übernimmt damit Verantwortung für die von ihr verursachten Emissionen.
- Die Technologie fördert das Umweltbewusstsein in der Gesellschaft.
- Das Verfahren erhöht die Chance, die Klimaziele der Schweiz zu erreichen.
- Die Speicherung ist nicht für immer (z. B. Abriss von Gebäuden).
- Das Verfahren fördert den Gebrauch von Beton, anstatt auf andere nachhaltigere Baumaterialien auszuweichen.
- CO₂ könnte während des Transports entweichen.
- Das Verfahren ist gesundheitsschädlich.
- Die CO₂ Speicherung im Beton hat negative Effekte auf die Umwelt.

Was würden Sie noch gerne über das Verfahren wissen?

[Textfeld]

Question block S3

In einem nächsten Schritt lernen Sie nun ein Verfahren zur CO₂-Abscheidung und -Speicherung kennen.

CO₂ wird in einer Biogasanlage in der Schweiz abgeschieden (CO₂ wird nach der Produktion von Biogas separiert). Das CO₂ wird per Lastwagen weiter transportiert und dann durch ein technisches Verfahren dauerhaft in Abbruchbeton gebunden (Mineralisierung). Der Beton kann unter

anderem für den Bau von Gebäuden oder Strassen benutzt werden. Alle diese Prozessschritte finden in der Schweiz statt. Dieses Verfahren entzieht CO₂ somit dauerhaft der Atmosphäre und trägt zum Erreichen der nationalen Klimaziele bei.

In dem nachfolgenden Q&A auf LinkedIn erhalten Sie weitere Informationen zu diesem Verfahren. Bitte lesen Sie das Q&A zuerst in Ruhe durch, bevor Sie die weiteren Fragen beantworten.



CO₂ Abscheidung und Speicherung
Cöng Ly • Sie
1 Woche • Bearbeitet • 

...

Das Interesse an [#CCTS](#) in der Bevölkerung ist gross. Daher möchten wir Ihnen hier einige wichtige Fragen zum [#DemoUpCARMA](#) Projekt beantworten:

- **WAS IST DIE GESAMTE CO₂-BILANZ DES VERFAHRENS?**
Jeder Schritt des Verfahrens braucht zusätzlich Material und Energie. Die CO₂-Effizienz des gesamten Verfahrens - Abscheidung, Transport und Speicherung - beträgt etwa 90%. Das heisst, für jede Tonne CO₂, die gespeichert wird, entstehen 100kg CO₂-Emissionen. Somit werden 900 kg CO₂-Emissionen schlussendlich langfristig vermieden.
- **WIE HOCH IST DIE TOTALE SPEICHERKAPAZITÄT, UND WIE VIEL CO₂ SOLL MIT DEM VERFAHREN GESPEICHERT WERDEN?**
Gemäss der langfristigen [#netzero](#) Klimastrategie der Schweiz belaufen sich die verbleibenden, schwer vermeidbaren Treibhausgasemissionen aus Industrie, Abfallwirtschaft und Landwirtschaft auf rund 12 Millionen Tonnen CO₂ pro Jahr. Im Jahr 2050 beträgt das Speicherpotenzial von CO₂ in Abbruchbeton rund 500'000 Tonnen CO₂ in der Schweiz.
- **WIE HOCH SIND DIE KOSTEN PRO TONNE GESPEICHERTES CO₂ IM GESAMTEN VERFAHREN, ALSO VON DER ABSCHIEDUNG BIS ZUR SPEICHERUNG?**
Die Kosten für eine flächendeckende Einführung dieser Technologie dürften bei einigen hundert Franken pro Tonne gespeichertem CO₂ liegen. Durch eine breite Anwendung der Technologie kann der Prozess optimiert und die Kosten gesenkt werden.
- **WIRD DIESES VERFAHREN BEREITS IN ANDEREN PROJEKTEN ANGEWENDET?**
Momentan betreibt die Firma Neustark in der Schweiz das Verfahren, wobei abgeschiedenes CO₂ im Beton gebunden wird. Weitere Unternehmen, die ähnliche Prozesse entwickeln, sind Zirkulit und Sika.

Haben Sie noch weitere Fragen zu [#CCTS](#), die sie gerne beantwortet haben möchten?

 Gefällt mir  Kommentar

Was ist Ihr erster Eindruck von diesem Verfahren?

[Textfeld]

Wie schätzen Sie Ihr Wissen über dieses Verfahren ein?

- ☐ Ich weiss nichts darüber.
- ☐ Ich weiss sehr wenig darüber.
- ☐ Ich weiss ein wenig darüber.
- ☐ Ich weiss einiges darüber.

- Ich weiss viel darüber.

Bitte beurteilen Sie ausgehend vom Q&A, ob folgende Aussagen korrekt sind oder nicht.

[Bitte kreuzen Sie alle korrekten Aussagen an.]

- Die Kosten können durch eine breite Anwendung der Technologie gesenkt werden.
- Es handelt sich um ein Verfahren, das noch nie vorher angewandt wurde.
- Durch dieses Verfahren können alle schwer vermeidbaren CO₂-Emissionen in der Schweiz abgeschieden und gespeichert werden.
- Das Verfahren ermöglicht es, schwer vermeidbare CO₂-Emissionen auszugleichen, auch unter Berücksichtigung der Emissionen während der Abscheidung, des Transports und der Speicherung.

Das Q&A ist:

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Informativ
- Verständlich
- Strukturiert
- Übersichtlich
- Ansprechend gestaltet
- Vertrauenswürdig

Wie stark stimmen Sie den folgenden Aussagen zu?

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Das Verfahren ist nützlich.
- Das Verfahren ist akzeptabel.
- Das Verfahren ist nötig, um die schwer zu vermeidenden CO₂-Emissionen auszugleichen.
- Das Verfahren ist nötig, um die Klimaziele der Schweiz zu erreichen.
- Das Verfahren muss von der Schweizer Bevölkerung befürwortet werden.
- Das Verfahren ist sicher.
- Das Verfahren ist sinnvoll.

Inwieweit unterstützen Sie dieses Verfahren?

- Lehne ich strikt ab.

- Lehne ich ab.
- Ich bin neutral
- Unterstütze ich.
- Unterstütze ich voll und ganz.
- Kann ich nicht sagen, da ich zu wenig weiss.

Wie stark stimmen Sie den folgenden Aussagen zu dem Verfahren zu?

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Es ist gut, dass es eine lokale Lösung zur Reduktion von CO2-Emissionen ist.
- Die Technologie erfordert keine Eingriffe in die Natur.
- Die Technologie hat ein geringes Risiko, dass CO2 entweichen kann.
- Der Ausbau der Technologie führt zu neuen Arbeitsplätzen.
- Die Industrie beteiligt sich an den Massnahmen zur Reduktion der CO2-Emissionen und übernimmt damit Verantwortung für die von ihr verursachten Emissionen.
- Die Technologie fördert das Umweltbewusstsein in der Gesellschaft.
- Das Verfahren erhöht die Chance, die Klimaziele der Schweiz zu erreichen.
- Die Speicherung ist nicht für immer (z. B. Abriss von Gebäuden).
- Das Verfahren fördert den Gebrauch von Beton, anstatt auf andere nachhaltigere Baumaterialien auszuweichen.
- CO2 könnte während des Transports entweichen.
- Das Verfahren ist gesundheitsschädlich.
- Die CO2 Speicherung im Beton hat negative Effekte auf die Umwelt.

Was würden Sie noch gerne über das Verfahren wissen?

[Textfeld]

Question block S4

In einem nächsten Schritt lernen Sie nun ein Verfahren zur CO2-Abscheidung und -Speicherung kennen.

CO2 wird in einer Biogasanlage in der Schweiz abgeschieden (CO2 wird nach der Produktion von Biogas separiert). Das CO2 wird per Lastwagen weiter transportiert und dann durch ein technisches Verfahren dauerhaft in Abbruchbeton gebunden (Mineralisierung). Der Beton kann unter anderem für den Bau von Gebäuden oder Strassen benutzt werden. Alle diese Prozessschritte finden in der Schweiz statt. Dieses Verfahren entzieht CO2 somit dauerhaft der Atmosphäre und trägt zum Erreichen der nationalen Klimaziele bei.

Im folgendem Text erhalten Sie weitere Informationen zu diesem Verfahren. Bitte lesen Sie den Text zuerst in Ruhe durch, bevor Sie die weiteren Fragen beantworten.

Gemäss der langfristigen Klimastrategie der Schweiz belaufen sich die verbleibenden, schwer vermeidbaren Treibhausgasemissionen aus Industrie, Abfallwirtschaft und Landwirtschaft auf rund 12 Millionen Tonnen CO₂ pro Jahr. Das oben beschriebene Verfahren der Speicherung von CO₂ in Abbruchbeton hat dabei ein Speicherpotenzial im Jahr 2050 von rund 500'000 Tonnen CO₂ in der Schweiz. Die Kosten für eine flächendeckende Einführung dieser Technologie dürften bei einigen hundert Franken pro Tonne gespeichertem CO₂ liegen. Durch eine breite Anwendung der Technologie kann aber der Prozess optimiert und die Kosten gesenkt werden, Die CO₂-Effizienz des gesamten Verfahrens - Abscheidung, Transport und Speicherung - beträgt etwa 90%. Das heisst, für jede Tonne CO₂, die gespeichert wird, entstehen 100kg CO₂-Emissionen. Somit werden 900 kg CO₂-Emissionen permanent entfernt. Das Verfahren wird momentan von Neustark in der Schweiz betrieben, wobei abgeschiedenes CO₂ im Beton gebunden wird. Weitere Unternehmen, die ähnliche Prozesse entwickeln, sind Zirkulit und Sika.

Was ist Ihr erster Eindruck von diesem Verfahren?

[Textfeld]

Wie schätzen Sie Ihr Wissen über dieses Verfahren ein?

- Ich weiss nichts darüber.
- Ich weiss sehr wenig darüber.
- Ich weiss ein wenig darüber.
- Ich weiss einiges darüber.
- Ich weiss viel darüber.

Bitte beurteilen Sie ausgehend vom Text, ob folgende Aussagen korrekt sind oder nicht.

[Bitte kreuzen Sie alle korrekten Aussagen an.]

- Die Kosten können durch eine breite Anwendung der Technologie gesenkt werden.
- Es handelt sich um ein Verfahren, das noch nie vorher angewandt wurde.
- Durch dieses Verfahren können alle schwer vermeidbaren CO₂-Emissionen in der Schweiz abgeschieden und gespeichert werden.
- Das Verfahren ermöglicht es, schwer vermeidbare CO₂-Emissionen auszugleichen, auch unter Berücksichtigung der Emissionen während der Abscheidung, des Transports und der Speicherung.

Der Fliesstext ist:

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Informativ

- Verständlich
- Strukturiert
- Übersichtlich
- Ansprechend gestaltet
- Vertrauenswürdig

Wie stark stimmen Sie den folgenden Aussagen zu?

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Das Verfahren ist nützlich.
- Das Verfahren ist akzeptabel.
- Das Verfahren ist nötig, um die schwer zu vermeidenden CO₂-Emissionen auszugleichen.
- Das Verfahren ist nötig, um die Klimaziele der Schweiz zu erreichen.
- Das Verfahren muss von der Schweizer Bevölkerung befürwortet werden.
- Das Verfahren ist sicher.
- Das Verfahren ist sinnvoll.

Inwieweit unterstützen Sie dieses Verfahren?

- Lehne ich strikt ab.
- Lehne ich ab.
- Ich bin neutral
- Unterstütze ich.
- Unterstütze ich voll und ganz.
- Kann ich nicht sagen, da ich zu wenig weiss.

Wie stark stimmen Sie den folgenden Aussagen zu dem Verfahren zu?

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Es ist gut, dass es eine lokale Lösung zur Reduktion von CO₂-Emissionen ist.
- Die Technologie erfordert keine Eingriffe in die Natur.
- Die Technologie hat ein geringes Risiko, dass CO₂ entweichen kann.
- Der Ausbau der Technologie führt zu neuen Arbeitsplätzen.
- Die Industrie beteiligt sich an den Massnahmen zur Reduktion der CO₂-Emissionen und übernimmt damit Verantwortung für die von ihr verursachten Emissionen.

- Die Technologie fördert das Umweltbewusstsein in der Gesellschaft.
- Das Verfahren erhöht die Chance, die Klimaziele der Schweiz zu erreichen.
- Die Speicherung ist nicht für immer (z. B. Abriss von Gebäuden).
- Das Verfahren fördert den Gebrauch von Beton, anstatt auf andere nachhaltigere Baumaterialien auszuweichen.
- CO2 könnte während des Transports entweichen.
- Das Verfahren ist gesundheitsschädlich.
- Die CO2 Speicherung im Beton hat negative Effekte auf die Umwelt.

Was würden Sie noch gerne über das Verfahren wissen?

[Textfeld]

Question block 3 - Fragen zu verschiedenen Transportmitteln:

Wie stark befürworten Sie den Transport des abgeschiedenen CO2 zu einem Speicherort mit den aufgeführten Transportmitteln?

[1=Befürworte ich überhaupt nicht, 5=Befürworte ich voll und ganz]

- Zug
- Schiff
- Pipeline (Rohrleitung)
- Lastwagen

Bitte bewerten Sie wie gut die Aussagen auf das Transportmittel "Zug" zutreffen.

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Ist sicher.
- Ist umweltfreundlich.
- Ist kostengünstig.
- Ist effizient.
- Sollte für den Transport von CO2 in der Schweiz in Betracht gezogen werden.
- Ist politisch umsetzbar.

Bitte bewerten Sie wie gut die Aussagen auf das Transportmittel "Schiff" zutreffen.

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Ist sicher.
- Ist umweltfreundlich.
- Ist kostengünstig.

- Ist effizient.
- Sollte für den Transport von CO2 in der Schweiz in Betracht gezogen werden.
- Ist politisch umsetzbar.

Bitte bewerten Sie wie gut die Aussagen auf das Transportmittel "Pipeline" zutreffen.

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Ist sicher.
- Ist umweltfreundlich.
- Ist kostengünstig.
- Ist effizient.
- Sollte für den Transport von CO2 in der Schweiz in Betracht gezogen werden.
- Ist politisch umsetzbar.

Bitte bewerten Sie wie gut die Aussagen auf das Transportmittel "Lastwagen" zutreffen.

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Ist sicher.
- Ist umweltfreundlich.
- Ist kostengünstig.
- Ist effizient.
- Sollte für den Transport von CO2 in der Schweiz in Betracht gezogen werden.
- Ist politisch umsetzbar.

Question block 4 - Allgemeine Fragen

Ich unterstütze die Speicherung von CO2 in der Schweiz, wenn:

[1 = Trifft überhaupt nicht zu, 5 = Trifft voll und ganz zu]

- das CO2 aus der Schweiz kommt.
- das CO2 aus Nachbarländern der Schweiz kommt.
- das CO2 aus Europa kommt.
- das CO2 ausserhalb von Europa kommt.
- ich nicht weiss, woher das CO2 kommt.

Inwieweit stimmen Sie den folgenden Aussagen zu?

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Die Klimaerwärmung hat schwerwiegende Folgen für Mensch und Umwelt.
- Der Klimaschutz ist wichtig für unsere Zukunft.
- Wir müssen das empfindliche Gleichgewicht des Klimas schützen.
- Ich mache mir um den Zustand des Klimas Sorgen.

Inwieweit stimmen Sie den folgenden Aussagen zu?

[1 = Ich stimme überhaupt nicht zu, 5 = ich stimme voll und ganz zu]

- Es ist spannend, neue Technologien auszuprobieren und sich darüber zu informieren.
- Neue Technologien machen das Leben besser.
- Mein Interesse an neuen Technologien ist sehr gross.
- Technische Innovationen helfen, effiziente Technologien zu entwickeln, die der Gesellschaft einen Nutzen bringen.

Wie viel Vertrauen haben Sie in die folgenden Akteure, welche am CO2 Abscheidungs- und Speicherungsprozess beteiligt sind?

[1 = Überhaupt kein Vertrauen, 5 = sehr grosses Vertrauen]

- Öffentliche Unternehmen
- Wissenschaftliche Forschungsinstitute (z. B. Universitäten, ETH)
- Regierung und amtliche Behörden
- Nichtregierungsorganisationen (NGOs)
- Industrieunternehmen (Betonproduzenten, Öl und Gas Produzenten, etc)

Wie schätzen Sie ihre politische Einstellung ein?

[1=Links, 5= rechts]

Question block 5

In welcher Form würden Sie zukünftig gerne Informationen zu dem Verfahren oder ähnlichen Verfahren erhalten?

- Infografik
- Kurzes Erklärvideo
- Interaktive Übersicht auf einer Webseite
- Informationsblatt (Flyer)
- Längerer Bericht mit detaillierter Information
- Zeitungsartikel
- Podcast
- Radiobeitrag

- Fernsehbeitrag
- Soziale Medien (z.B. TikTok oder Instagram)
- Anderes: [Textfeld]

Von wem würden Sie zukünftig gerne Informationen zu diesem Verfahren erhalten?

- Wissenschaftler/innen
- Bundesämter
- Industrievertreter/innen
- Aktivist/innen
- Politiker/innen
- Umweltverbände (NGOs)
- Andere

Question block 6 - Fragen zu Ihrer Person:

- **In welchem Kanton sind Sie Wohnhaft?**
- Aargau
- Appenzell Innerrhoden
- Appenzell Ausserrhoden
- Bern
- Basel-Landschaft
- Basel-Stadt
- Freiburg
- Genf
- Glarus
- Graubünden
- Jura
- Luzern
- Neuenburg
- Nidwalden
- Obwalden
- St. Gallen
- Schaffhausen

- Solothurn
- Schwyz
- Thurgau
- Tessin
- Uri
- Waadt
- Wallis
- Zug
- Zürich

Was ist Ihr höchster schulischer Abschluss?

- Universität
- Fachhochschule
- Höhere Fachschule
- Maturität (Berufsmaturität oder gymnasiale Maturität)
- Lehre
- Obligatorische Schule
- Andere, bitte spezifizieren: Textlinie

Sind Sie derzeit erwerbstätig oder in Ausbildung?

- In Ausbildung ohne Vergütung (z. B. Schule, Universitätsstudium)
- In Ausbildung mit Vergütung (z. B. Berufslehre, Doktorat mit Anstellung)
- Vollzeit erwerbstätig (80-100%)
- Teilzeit erwerbstätig (weniger als 80%)
- Hauptberuflich Hausarbeit leistend
- Zurzeit ohne Arbeit
- Pensioniert

Haben Sie abschliessend noch irgendwelche Anmerkungen?

[Textfeld]

Besten Dank für Ihre Teilnahme! Ihre Antworten wurden erfolgreich gespeichert.

Falls Sie mehr zum Projekt DemoUpCARMA erfahren wollen, finden Sie weitere Informationen hier: <http://www.demoupcarma.ethz.ch/de/home/>

Mit freundlichen Grüßen,
 Dr. Irina Dallo, Wissenschaftliche Mitarbeiterin an der ETH Zürich
 Công Ly, Master-Student an der ETH Zürich

B-3: Descriptive analysis – overview table

The values are aggregated over all participants. For the questions where we indicate the mean and standard deviation (SD), we used a 5-point Likert scale. For the interpretation questions, the correct answers are highlighted in green.

Items	n	%	Mean	SD	Cronbachs alpha
Dependent variables					
General Familiarity:					
Wie schätzen Sie Ihr Wissen über CO2 Abscheidungs- und Speicherungstechnologien ein? (1= <i>Ich weiss nichts darüber</i> , 5= <i>Ich weiss viel darüber</i>)			2.46	0.927	
General Support:					
Würden Sie im Allgemeinen CO2 Abscheidungs- und Speicherungstechnologien unterstützen? (1= <i>lehne ich strikt ab</i> , 5= <i>Unterstütze ich voll und ganz</i>)			3.61	0.894	
Specific familiarity: Wie schätzen Sie Ihr Wissen über dieses Verfahren ein?					
(1= <i>Ich weiss nichts darüber</i> , 5= <i>Ich weiss viel darüber</i>)			2.10	0.912	
Specific support: Inwieweit unterstützen Sie dieses Verfahren?					
(1= <i>Lehne ich strikt ab</i> , 5= <i>unterstütze ich voll und ganz</i>)			3.47	1.065	
General Acceptance: Wie stark stimmen Sie den folgenden Aussagen zu? (1= <i>stimme überhaupt nicht zu</i> , 5= <i>stimme voll und ganz zu</i>)					
Das Verfahren ist nützlich.			3.5	0.917	0.91
Das Verfahren ist akzeptabel.			3.65	1.149	
Das Verfahren ist nötig, um die schwer zu vermeidenden CO2-Emissionen auszugleichen.			3.51	1.118	
			3.45	1.133	

Items	n	%	Mean	SD	Cronbachs alpha
Das Verfahren ist nötig, um die Klimaziele der Schweiz zu erreichen.			3.50	1.182	
Das Verfahren muss von der isländischen Bevölkerung befürwortet werden.			3.71	1.219	
Das Verfahren ist sicher.			3.20	1.019	
Das Verfahren ist sinnvoll.			3.46	1.172	
Transport Evaluation					
Wie stark befürworten Sie den Transport des abgeschiedenen CO2 zu einem Speicherort mit den aufgeführten Transportmitteln? (1= <i>stimme überhaupt nicht zu</i> , 5= <i>stimme voll und ganz zu</i>)			3.05	0.82	
Zug			3.68	1.257	
Schiff			2.83	1.270	
Pipeline			3.29	1.254	
Lastwagen			2.41	1.179	
Bitte bewerten Sie wie gut die Aussagen auf das Transportmittel " Zug " zutreffen. (1= <i>stimme überhaupt nicht zu</i> , 5= <i>stimme voll und ganz zu</i>)			3.66	0.918	
Ist sicher.			3.67	1.060	
Ist umweltfreundlich.			3.86	1.049	
Ist kostengünstig.			3.42	1.072	
Ist effizient.			3.64	1.087	
Sollte für den Transport von CO2 in der Schweiz in Betracht gezogen werden.			3.73	1.159	
Ist politisch umsetzbar.			3.66	1.109	
Bitte bewerten Sie wie gut die Aussagen auf das Transportmittel " Schiff " zutreffen. (1= <i>stimme überhaupt nicht zu</i> , 5= <i>stimme voll und ganz zu</i>)			2.64	0.931	
Ist sicher.			2.95	1.132	
Ist umweltfreundlich.			2.52	1.196	
Ist kostengünstig.			2.64	1.095	
Ist effizient.			2.69	1.107	

Items	n	%	Mean	SD	Cronbachs alpha
Sollte für den Transport von CO2 in der Schweiz in Betracht gezogen werden.			2.33	1.163	
Ist politisch umsetzbar.			2.70	1.120	
Bitte bewerten Sie wie gut die Aussagen auf das Transportmittel "Pipeline" zutreffen. (1=stimme überhaupt nicht zu, 5=stimme voll und ganz zu)			3.25	0.931	
Ist sicher.			3.39	1.125	
Ist umweltfreundlich.			3.34	1.201	
Ist kostengünstig.			2.84	1.176	
Ist effizient.			3.77	1.089	
Sollte für den Transport von CO2 in der Schweiz in Betracht gezogen werden.			3.22	1.236	
Ist politisch umsetzbar.			2.96	1.104	
Bitte bewerten Sie wie gut die Aussagen auf das Transportmittel "Lastwagen" zutreffen. (1=stimme überhaupt nicht zu, 5=stimme voll und ganz zu)			2.58	0.893	
Ist sicher.			2.68	1.116	
Ist umweltfreundlich.			1.95	0.946	
Ist kostengünstig.			2.66	1.081	
Ist effizient.			2.66	1.146	
Sollte für den Transport von CO2 in der Schweiz in Betracht gezogen werden.			2.54	1.158	
Ist politisch umsetzbar.			2.99	1.188	
Independant Variables					
CO2 Origin: Ich unterstütze die Speicherung von CO2 in der Schweiz, wenn: (1=stimme überhaupt nicht zu, 5=stimme voll und ganz zu)			2.62	0.919	
das CO2 aus der Schweiz kommt.			3.94	1.083	
das CO2 aus Nachbarländern der Schweiz kommt.			2.69	1.248	
das CO2 aus Europa kommt.			2.47	1.207	
das CO2 ausserhalb von Europa kommt.			1.98	1.170	

Items	n	%	Mean	SD	Cronbachs alpha
ich nicht weiss, woher das CO2 kommt.			2.02	1.272	
Climate change concern: Inwieweit stimmen Sie den folgenden Aussagen zu? (1=stimme überhaupt nicht zu, 5=stimme voll und ganz zu)			3.99	1.032	0.94
Die Klimaerwärmung hat schwerwiegende Folgen für Mensch und Umwelt.			4.02	1.107	
Der Klimaschutz ist wichtig für unsere Zukunft.			4.15	1.072	
Wir müssen das empfindliche Gleichgewicht des Klimas schützen.			4.08	1.070	
Ich mache mir um den Zustand des Klimas Sorgen.			3.71	1.237	
Technological affinity: Inwieweit stimmen Sie den folgenden Aussagen zu? (1=stimme überhaupt nicht zu, 5=stimme voll und ganz zu)			3.54	0.887	0.88
Es ist spannend, neue Technologien auszuprobieren und sich darüber zu informieren.			3.81	1.029	
Neue Technologien machen das Leben besser.			3.36	1.029	
Mein Interesse an neuen Technologien ist sehr gross			3.30	1.119	
Technische Innovationen helfen, effiziente Technologien zu entwickeln, die der Gesellschaft einen Nutzen bringen.			3.67	0.972	
Trust in Stakeholders: Wie viel Vertrauen haben Sie in die folgenden Akteure, welche am CO2 Abscheidungs- und Speicherungsprozess beteiligt sind? (1= überhaupt kein Vertrauen, 5= sehr grosses Vertrauen)			3.08	0.815	0.84
Öffentliche Unternehmen			3.06	0.962	
Wissenschaftliche Forschungsinstitute (z. B. Universitäten, ETH)			3.75	1.080	
Regierung und amtliche Behörden			2.99	1.081	
Nichtregierungsorganisationen (NGOs)			2.99	1.073	
Industrieunternehmen (Betonproduzenten, Öl und Gas Produzenten, etc)			2.63	1.044	
Political attitude: Wie schätzen Sie ihre politische Einstellung ein?			3.03	0.923	

Items	n	%	Mean	SD	Cronbachs alpha

(1=links, 5= rechts)

Media evaluation:

Design: Die Infografik ist: (1=stimme überhaupt nicht zu, 5=stimme voll und ganz zu)

Informativ			3.50	0.886
Verständlich			3.68	0.974
Strukturiert			3.41	1.065
Übersichtlich			3.61	0.999
Ansprechend gestaltet			3.55	1.036
Vertrauenswürdig			3.37	1.078
			3.39	1.078

Comprehension: Bitte beurteilen Sie ausgehend von der Infografik, ob folgende Aussagen korrekt sind oder nicht. (0=falsche Antwort, 1=korrekte Antwort) (*n indicates the sum of correct answers*)

Die Kosten können durch eine breite Anwendung der Technologie gesenkt werden.	297	59
Es handelt sich um ein Verfahren, das noch nie vorher angewandt wurde.	394	78.3
Durch dieses Verfahren können alle schwer vermeidbaren CO2-Emissionen in der Schweiz abgeschieden und gespeichert werden.	347	68.9
Das Verfahren ermöglicht es, schwer vermeidbare CO2-Emissionen auszugleichen, auch unter Berücksichtigung der Emissionen während der Abscheidung, des Transports und der Speicherung.	306	60.8

Source preference: Von wem würden Sie zukünftig gerne Informationen zu diesem Verfahren erhalten?

Wissenschaftler/innen	381	75.7
Bundesämter	246	48.9
Industrievertreter/innen	117	23.3
Aktivist/innen	54	10.7
Politiker/innen	76	15.1

Items	n	%	Mean	SD	Cronbachs alpha
Umweltverbände (NGOs)	229	45.5			
Andere	25	4.97			
Product preference: In welcher Form würden Sie zukünftig gerne Informationen zu dem Verfahren oder ähnlichen Verfahren erhalten?					
Infografik	138	27.4			
Kurzes Erklärvideo	271	53.8			
Interaktive Übersicht auf einer Webseite	158	31.4			
Informationsblatt (Flyer)	141	28.0			
Längerer Bericht mit detaillierter Information	127	25.3			
Zeitungsartikel	186	36.9			
Podcast	54	10.7			
Radiobeitrag	105	20.9			
Fernsehbeitrag	291	57.9			
Soziale Medien (z.B. TikTok oder Instagram)	87	17.3			
Anderes:	21	4.17			
Sociodemographic data					
Living Place: In welchem Kanton sind Sie Wohnhaft?					
	503	100			
Aargau	57	11.3			
Appenzell Innerrhoden	3	0.6			
Appenzell Ausserrhoden	4	0.8			
Bern	93	18.5			
Basel-Landschaft	26	5.2			
Basel-Stadt	10	2.0			
Freiburg	6	1.2			
Genf	0	0			
Glarus	1	0.2			
Graubünden	19	3.8			
Jura	0	0			
Luzern	32	6.4			
Neuenburg	1	0.2			

Items	n	%	Mean	SD	Cronbachs alpha
Obwalden	0	0			
Nidwalden	8	1.6			
St. Gallen	30	6.0			
Schaffhausen	10	2.0			
Solothurn	17	3.4			
Schwyz	7	1.4			
Thurgau	31	6.2			
Tessin	6	1.2			
Uri	2	0.4			
Waadt	1	0.2			
Wallis	6	1.2			
Zug	5	1.0			
Zürich	128	25.4			
Education: Was ist Ihr höchster schulischer Abschluss?	503	100			
University	65	12.9			
University of applied sciences	69	13.7			
Technical college	79	15.7			
Matura	62	12.3			
Apprenticeship	202	40.2			
Compulsory school	20	4.0			
Other	6	1.2			
Occupation: Sind Sie derzeit erwerbstätig oder in Ausbildung?	503	100			
In Ausbildung ohne Vergütung (z. B. Schule, Universitätsstudium)	15	3.0			
In Ausbildung mit Vergütung (z. B. Berufslehre, Doktorat mit Anstellung)	7	1.4			
Vollzeit erwerbstätig (80-100%)	219	43.5			
Teilzeit erwerbstätig (weniger als 80%)	105	20.9			
Hauptberuflich Hausarbeit leistend	22	4.4			
Zurzeit ohne Arbeit	20	4.0			
Pensioniert	115	22.9			

Items	n	%	Mean	SD	Cronbachs alpha
Gender:	503	100			
female	251	49.9			
male	249	49.5			
divers	3	0.6			
Age:	503	100			
18-30	95	18.9			
31-42	107	21.3			
43-54	98	19.5			
55-66	101	20.1			
67-100	101	20.1			

Pathways-specific-data	n		%		MEAN		SD		Cronbachs alpha
ITEMS	CH	IS	CH	IS	CH	IS	CH	IS	
General Acceptance: Wie stark stimmen Sie den folgenden Aussagen zu?	241	262	47.9	52.1	3.59	3.41	0.925	0.903	
Das Verfahren ist nützlich.					3.77	3.54	1.16	1.130	
Das Verfahren ist akzeptabel.					3.68	3.36	1.108	1.108	
Das Verfahren ist nötig, um die schwer zu vermeidenden CO2-Emissionen auszugleichen.					3.57	3.34	1.135	1.123	
Das Verfahren ist nötig, um die Klimaziele der Schweiz zu erreichen.					3.63	3.37	1.172	1.179	
Das Verfahren muss von der isländischen/schweizer Bevölkerung befürwortet werden.					3.59	3.81	1.208	1.223	
Das Verfahren ist sicher.					3.30	3.11	1.047	0.986	
Das Verfahren ist sinnvoll.					3.63	3.31	1.179	1.144	

Pathways-specific-data	n		%		MEAN		SD	Cronbachs alpha
Specific familiarity: Wie schätzen Sie Ihr Wissen über dieses Verfahren ein? (1=Ich weiss nichts darüber, 5= Ich weiss viel darüber)	241	262	47.9	52.1	2.18	2.03	0.929	0.892
Specific support: Inwieweit unterstützen Sie dieses Verfahrens? (1=Lehne ich strikt ab, 5=unterstütze ich voll und ganz)	224	238	44.5	47.3	3.58	3.36	1.042	1.076
Risk perception : Wie stark stimmen Sie den folgenden Aussagen zu dem Verfahren zu?	241	262			3.034	3.23	0.6938	0.717
CO2 könnte aus der Gesteinsformation an die Oberfläche entweichen.						3.24		0.993
Die Schweiz exportiert ihre Probleme nach Island.						3.50		1.183
Die geopolitischen Abhängigkeiten könnten zum Scheitern des Projektes führen.						3.51		0.925
Die CO2 Speicherung im Untergrund hat negative Effekte auf das Ökosystem im Untergrund (z. B., Trinkwasserverschmutzung, Lebewesen, Biodiversität).						3.17		0.968
Grössere Naturereignisse wie Erdbeben oder Vulkanausbrüche können zum Entweichen des CO2 führen.						3.42		0.990
CO2 kann während des Transports entweichen.					3.09	3.27	1.001	1.067
Das Verfahren ist gesundheitsschädlich.					2.57	2.55	0.993	0.924
Das Verfahren fördert den Gebrauch von Beton, anstatt auf andere					3.43		1.093	

Pathways-specific-data	n		%	MEAN		SD	Cronbachs alpha	
nachhaltigere Baumaterialien auszuweichen.								
Die Speicherung ist nicht für immer (z. B. Abriss von Gebäuden).				3.36		1.019		
Die CO2 Speicherung im Beton hat negative Effekte auf die Umwelt.				2.72		1.046		
Benefit Perception: Wie stark stimmen Sie den folgenden Aussagen zu dem Verfahren zu?	241	262		3.39	3.07	0.781	0.754	0.75
Der Ausbau dieses Verfahrens führt zu neuen Arbeitsplätzen.				3.54	3.56	1.003	0.935	
Die Industrie beteiligt sich an den Massnahmen zur Reduktion der CO2-Emissionen und übernimmt damit Verantwortung für die von ihr verursachten Emissionen.				3.38	3.14	1.054	0.997	
Dieses Verfahren fördert das Umweltbewusstsein in der Gesellschaft.				3.19	2.79	1.170	1.185	
Das Verfahren erhöht die Chance, die Klimaziele der Schweiz zu erreichen.				3.64	3.53	1.106	1.059	
Die Technologie hat ein geringes Risiko, dass CO2 entweichen kann.				3.17		0.966		
Die Technologie erfordert keine Eingriffe in die Natur.				3.09	2.31	1.098	1.148	
Es ist gut, dass es eine lokale Lösung zur Reduktion von CO2-Emissionen ist.				3.71			1.072	
Local Acceptance (Island): Momentan wird auch geprüft, ob CO2 bei uns in der Schweiz in geeigneten geologischen Formationen gespeichert werden könnte. Wie stark stimmen Sie den folgenden Aussagen zu?		262			3.02		1,08	0.86

Pathways-specific-data	n	%	MEAN	SD	Cronbachs alpha
(1=Stimme überhaupt nicht zu, 5=stimme voll und ganz zu)					
Ich würde den Bau einer Speicheranlage in meiner Nachbarschaft akzeptieren.			2.87	1.269	
Ich denke, eine Speicheranlage in meiner Nachbarschaft würde keine Probleme bereiten.			2.82	1.221	
Ich wäre besorgt, wenn eine Speicheranlage in meiner Nachbarschaft gebaut würde.			2.98	1.283	
Ich würde gegen den Bau einer Speicheranlage in meiner Nachbarschaft protestieren.			3.42	1.341	

B-4: Personal factors (independent variables)

We assessed four personal factors:

1) Climate change concern:

To what extent do you agree with the following statements? [1=strongly disagree to 5=strongly agree]	Mean	SD
Climate Change has serious consequences for people and the environment.	4.02	1.11
Climate protection is important for the future.	4.15	1.07
We must protect the delicate balance of the climate.	4.08	1.07
I am concerned about the state of the climate.	3.71	1.24

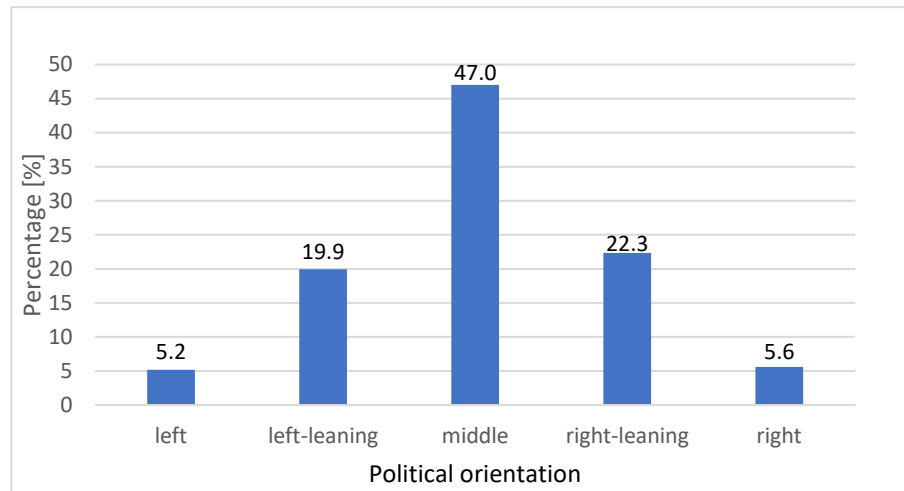
2) Technological affinity:

To what extent do you agree with the following statements? [1=strongly disagree to 5=strongly agree]	Mean	SD
It is exciting to try out new technologies and learn about them.	3.81	1.03
New technologies make life better.	3.36	1.03
I am very interested in new technologies.	3.30	1.12
Technical innovations help to develop efficient technologies that benefit society.	3.67	0.97

3) Trust in stakeholders:

How much trust do you have in the following stakeholders involved in the CO2 capture and storage process? [1=no trust at all to 5=very high trust]	Mean	SD
Public companies	3.06	0.96
Scientific research institutes (e.g. universities, ETH)	3.75	1.08
Government and authoritative agencies	2.99	1.08
Non-governmental organizations (NGOs)	2.99	1.07
Industrial companies (e.g. concrete producers etc.)	2.63	1.04

4) Political orientation:



B-5: ISLAND: One-way ANOVAs to analyse the effect of the independent, categorical variables on the independent variables

	Specific acceptance			Specific support			Perceived risks (summative mean)			Perceived benefits (summative mean)			Comprehension		
	ANOVA			ANOVA			ANOVA			ANOVA			ANOVA		
	F(4, 257) = 3.096, p = 0.016			F(4, 233) = 4.726, p = 0.002			F(4,257) = 1.142, p = 0.337			F(4,257)= 3.325, p=0.011			F(4,257) = 0.918, p = 0.454		
Age category	n	M	SD	n	M	SD	n	M	SD	n	M	SD	n	M	SD
18-30 ^a	55	3.62 ^d	0.73	50	3.62 ^d	0.90	55	3.18	0.59	55	3.20 ^d	0.67	55	0.71	0.26
31-42 ^b	51	3.52	1.04	47	3.38	1.23	51	3.26	0.65	51	3.11	0.76	51	0.69	0.25
43-54 ^c	48	3.43	0.80	45	3.44 ^d	0.97	48	3.27	0.72	48	3.19 ^d	0.66	48	0.68	0.28
55-66 ^d	52	3.05 ^a	0.93	46	2.80 ^{a,c,e}	1.22	52	3.39	0.80	52	2.74 ^{a,c}	0.77	52	0.62	0.25
67-100 ^e	56	3.40	0.92	50	3.50 ^d	0.89	56	3.11	0.79	56	3.10	0.81	56	0.67	0.29
Total	262	3.41	0.90	238	1.08	0.70	262	3.23	0.72	262	3.07	0.75	262	0.67	0.26
	ANOVA			ANOVA			ANOVA			ANOVA			ANOVA		

	F(21,240) = 0.688, p = 0.844			F(20,217) = 0.740, p = 0.782			F(21,240) = 0.869, p = 0.631			F(21,240) = 1.231, p = 0.225			F(21,240) = 1.017, p = 0.444		
Living canton	n	M	SD	n	M	SD	n	M	SD	n	M	SD	n	M	SD
Aargau	20	3.13	0.83	18	3.17	1.04	20	3.40	0.62	20	2.77	0.70	20	0.69	0.21
Appenzell Inerrhoden	1	3.71	-	1	4.00	-	1	3.14	.	1	3.40	.	1	.50	.
Appenzell Ausserrhoden	2	3.36	0.51	1	3.00	-	2	3.50	0.71	2	3.50	0.71	2	0.38	0.18
Bern	51	3.44	0.99	49	3.39	1.13	51	3.23	0.78	51	3.19	0.79	51	0.72	0.26
Basel-Country	13	3.30	0.99	12	3.33	1.07	13	3.50	0.64	13	2.85	0.76	13	.56	0.27
Basel-City	3	3.52	0.46	2	3.50	9.71	3	3.29	0.29	3	3.33	0.58	3	0.67	0.14
Fribourg	3	4.29	0.74	2	4.5	0.71	3	2.71	0.87	3	3.67	.64	3	0.75	0.00
Geneva	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-
Glarus	1	2.86	-	1	1.00	-	1	4.1	.	1	1.80	.	1	0.75	.
Graubünden	12	3.54	0.67	12	0.90	0.26	12	3.34	0.62	12	3.32	0.67	12	0.76	0.31
Jura	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-
Lucerne	15	3.37	0.75	13	3.46	1.13	15	3.12	0.69	15	3.07	0.59	15	0.52	0.31
Neuchâtel	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-
Nidwalden	5	3.43	0.467	5	3.20	1.48	5	3.14	0.63	5	2.76	0.89	5	.75	0.18
Obwalden	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-
St. Gallen	19	3.23	0.83	16	2.88	0.96	19	3.47	0.66	19	2.91	0.55	19	0.78	0.23
Schaffhausen	5	3.86	1.34	5	4.00	1.22	5	2.83	0.42	5	3.80	0.63	5	.75	0.31
Solothurn	7	3.49	0.53	7	3.71	0.49	7	2.76	0.62	7	3.14	0.40	7	0.64	0.19
Schwyz	2	3.14	1.01	1	3.99	-	2	3.00	0.61	2	2.90	0.14	2	.50	0.35
Thurgau	18	3.40	0.93	16	3.38	1.26	18	3.22	0.76	18	3.02	0.72	18	0.69	0.29
Ticino	3	2.48	1.28	2	3.50	0.71	3	2.38	1.21	3	2.47	1.27	3	0.67	0.14
Uri	2	2.93	0.10	2	3.00	0.00	2	3.21	0.51	2	3.00	0.28	2	0.75	0.00
Vaud	1	3.14	-	0	-	-	1	3.00	.	1	3.60	.	1	0.25	.
Valais	1	2.14	-	1	4.00	-	1	3.29	.	1	4.00	.	1	0.75	.
Zug	2	3.36	0.10	2	3.50	0.71	2	3.21	0.91	2	2.30	0.14	2	0.88	0.18
Zurich	76	3.51	0.95	70	3.37	1.11	76	3.23	0.75	76	3.08	0.82	76	0.66	0.28
Total	262	3.41	0.90	238	3.36	1.08	262	3.24	0.72	262	3.07	0.75	262	0.67	0.26
	ANOVA			ANOVA			ANOVA			ANOVA			ANOVA		

	F(1,257) = 2.405, p = 0.122			F(1,233) = 1.646, p = 0.201			F(1,257) = 0.360, p = 0.549			F(1,257) = 2.722, p = 0.100			F(1,257) = 2.921, p = 0.089		
Gender	n	M	SD	n	M	SD	n	M	SD	n	M	SD	n	M	SD
female	136	3.48	0.87	120	3.44	1.05	136	3.27	0.71	136	3.14	0.73	136	0.64	0.28
male	123	3.31	0.94	115	3.26	1.11	123	3.21	0.71	123	2.99	0.79	123	0.70	0.24
Total	259	3.40	0.91	235	3.35	1.08	259	3.24	0.71	259	3.10	0.75	259	0.67	0.26
	ANOVA F(6,255) = 2.189, p = 0.045			ANOVA F(6,231) = 2.022, p = 0.064			ANOVA F(6,255) = 0.754, p = 0.607			ANOVA F(6,255) = 1.104, p = 0.360			ANOVA F(6,255) = 1.595, p = 0.149		
Education	n	M	SD	n	M	SD	n	M	SD	n	M	SD	n	M	SD
University ^a	36	3.47	1.02	32	3.5	1.27	36	3.23	0.70	36	3.23	0.87	36	0.70	0.31
University of applied sciences ^b	30	3.53	0.91	28	3.57	1.03	30	3.27	0.70	30	3.10	0.76	30	0.73	0.24
Higher technical school ^c	40	3.37	0.92	39	3.367	1.04	40	3.18	0.67	40	3.05	0.63	40	0.73	0.25
Matura ^d	43	3.70 ^e	0.81	40	3.68	0.76	43	3.12	0.74	43	3.13	0.71	43	0.69	0.28
Apprenticeship ^e	104	3.20 ^d	0.88	90	3.08	1.12	104	3.32	0.74	104	2.95	0.77	104	0.62	0.25
Compulsary school ^f	8	3.86	0.46	8	3.63	0.92	8	2.96	0.72	8	3.45	0.65	8	0.69	0.26
Other ^g	1	3.29	-	1	3.00	-	1	3.71	.	1	3.00	.	1	1.00	.
Total	262	3.40	0.90	238	3.36	1.08	262	3.24	0.72	262	3.07	0.75	262	0.67	0.26
	ANOVA F(6,255) = 0.676, p = 0.669			ANOVA F(6,231) = 1.073, p = 0.379			ANOVA F(6,255) = 1.700, p = 0.121			ANOVA F(6,255) = 0.973, p = 0.444			ANOVA F(6,255) = 0.891, p = 0.502		
Occupation	n	M	SD	n	M	SD	n	M	SD	n	M	SD	n	M	SD
In training without remuneration	11	3.57	0.77	10	4.0	0.67	11	2.88	.58	11	3.02	0.44	11	0.80	0.25
In training with remuneration	5	3.69	0.92	5	3.20	0.84	5	2.83	.33	5	3.16	0.65	5	0.80	0.33
Employed full-time (80-100%)	108	3.31	0.96	97	3.23	1.21	108	3.31	.67	108	3.01	0.80	108	0.68	0.25
Part-time employed (less than 80%)	52	3.56	0.70	49	3.47	0.96	52	3.25	.74	52	3.15	0.59	52	0.66	0.28
Full-time housework	11	3.55	1.11	11	3.27	1.35	11	3.47	.44	11	3.07	0.74	11	0.73	0.18
Currently unemployed	13	3.46	0.80	12	3.17	1.11	13	3.47	.55	13	3.49	0.71	13	0.69	0.27
Retired	62	3.35	0.96	54	3.44	0.90	62	3.11	.84	62	3.01	0.85	62	0.64	0.29
Total	262	3.40	0.90	238	3.36	1.08	262	3.24	.72	262	3.07	0.754	262	0.67	0.26

B-6: Switzerland: One-way ANOVAs to analyse the effect of the independent, categorical variables on the independent variables

	Specific acceptance			Specific support			Perceived risks (summative mean)			Perceived benefits (summative mean)			Comprehension		
	ANOVA			ANOVA			ANOVA			ANOVA			ANOVA		
	F(4,235) = 2.360, p = 0.054			F(4,218) = 1.222, p = 0.302			F(4,235) = 0.757, p = 0.554			F(4,235) = 1.041, p = 0.387			F(4,235) = 1.516, p = 0.198		
Age category	n	M	SD	n	M	SD	n	M	SD	n	M	SD	n	M	SD
18-30	40	3.76	0.12	36	3.69	0.75	40	2.96	0.70	40	3.40	0.54	40	0.71	0.30
31-42	56	3.80	0.10	55	3.78	0.79	56	3.16	0.60	56	3.45	0.69	56	0.70	0.27
43-54	50	3.67	0.12	46	3.59	1.20	50	2.98	0.78	50	3.50	0.82	50	0.67	0.26
55-66	49	3.42	0.15	46	3.39	1.13	49	3.05	0.67	49	3.35	0.84	49	0.65	0.30
67-100	45	3.34	0.17	40	3.42	1.23	45	2.99	0.73	45	3.20	0.94	45	0.58	0.29
Total	240	3.60	0.60	233	3.58	1.04	240	3.03	0.69	240	3.39	0.78	240	0.66	0.29
	ANOVA			ANOVA			ANOVA			ANOVA			ANOVA		
	F(19,221) = 0.806, p = 0.699			F(19,204) = 0.838, p = 0.660			F(19,221) = 1.579, p = 0.063			F(19,221) = 0.727, p = 0.790			F(25,560) = 1.224, p = 0.210		
Living canton	n	M	SD	n	M	SD	n	M	SD	n	M	SD	n	M	SD
Aargau	37	3.64	0.73	34	3.65	0.98	37	2.98	0.65	37	3.47	0.75	37	0.67	0.29
Appenzell Inerrhoden	2	2.50	1.11	2	2.50	0.71	2	3.10	0.99	2	3.50	0.91	2	0.88	0.18
Appenzell Ausserrhoden	2	4.14	1.21	2	4.00	1.41	2	3.00	0.57	2	3.21	0.10	2	0.75	0.00
Bern	42	3.51	0.83	41	3.44	0.98	42	2.92	0.69	42	3.37	0.65	42	0.63	0.32
Basel-Country	13	3.58	0.86	13	3.54	0.78	13	2.77	0.85	13	3.46	0.86	13	0.69	0.29
Basel-City	7	3.55	1.12	6	3.50	1.52	7	3.17	0.39	7	3.29	1.00	7	0.46	0.22
Fribourg	3	4.48	0.82	3	4.67	0.58	3	2.60	1.25	3	3.86	0.52	3	1.00	0.00
Geneva	0	-	-	0	-	-	0	-	-	0	-	-	0		
Glarus	0	-	-	0	-	-	0	-	-	0	-	-	0		
Graubünden	7	3.38	1.17	7	3.57	0.79	7	2.74	0.43	7	2.92	0.88	7	0.68	0.35
Jura	0	-	-	0	-	-	0	-	-	0	-	-	0		
Lucerne	17	3.72	0.92	15	3.60	1.06	17	3.46	0.85	17	3.40	0.69	17	0.63	0.29
Neuchâtel	1	3.86	-	1	4.00	-	1	3.00	.	1	3.86	.	1	1.00	.
Nidwalden	3	4.05	0.84	3	4.00	1.00	3	2.60	1.04	3	3.62	0.70	3	0.92	0.14

Obwalden	0	-	-	0	-	-	0	-	-	0	-	-	0		
St. Gallen	11	3.10	1.35	11	2.91	1.22	11	3.42	0.58	11	3.00	0.62	11	0.66	0.28
Schaffhausen	5	3.43	0.75	5	3.40	0.89	5	3.60	0.84	5	3.11	1.01	5	0.60	0.29
Solothurn	10	3.51	0.74	9	3.67	0.71	10	2.90	0.73	10	3.29	0.62	10	0.68	0.29
Schwyz	5	3.49	1.56	5	3.60	1.67	5	3.40	0.84	5	3.46	1.13	5	0.50	0.25
Thurgau	13	3.82	0.58	11	3.91	0.83	13	2.99	0.31	13	3.43	0.52	13	0.69	0.25
Ticino	3	2.86	1.22	2	2.50	2.12	3	4.00	0.92	3	2.71	1.31	3	0.25	0.00
Uri	0	-	-	0	-	-	0	-	-	0	-	-	0		
Vaud	0	-	-	0	-	-	0	-	-	0	-	-	0		
Valais	5	3.51	0.37	5	3.80	1.1	5	3.16	0.62	5	3.43	0.53	5	0.60	0.34
Zug	3	4	0.71	3	3.67	1.17	3	3.13	0.50	3	4.14	0.80	3	0.50	0.25
Zurich	52	3.69	1.07	46	3.70	1.17	52	2.96	0.62	52	3.46	0.94	52	0.71	0.26
Total	241	3.59	0.92	224	3.58	1.04	241	3.03	0.69	241	3.39	0.78	241	0.66	0.29
ANOVA				ANOVA			ANOVA			ANOVA			ANOVA		
F(1,239) = 1.816, p = 0.179				F(1,222) = 1.305, p = 0.254			F(1,239) = 0.043, p = 0.837			F(1,239) = 0.404, p = 0.526			F(1,239) = 3.511, p = 0.062		
Gender	n	M	SD	n	M	SD	n	M	SD	n	M	SD	n	M	SD
female	115	3.68	0.78	107	3.66	0.89	115	3.02	0.63	115	3.42	0.68	115	0.70	0.28
male	126	3.52	1.04	117	1.16	0.11	126	3.04	0.75	126	3.36	0.86	126	0.63	0.29
Total	241	3.60	0.92	224	1.04	0.70	241	3.03	0.69	241	3.39	0.78	241	0.66	0.29
ANOVA				ANOVA			ANOVA			ANOVA			ANOVA		
F(6,234) = 1.363, p = 0.230				F(6,217) = 3.043, p = 0.007			F(6,234) = 0.401, p = 0.878			F(6,234) = 1.053, p = 0.391			F(6,234) = 2.422, p = 0.27		
Education	n	M	SD	n	M	SD	n	M	SD	n	M	SD	n	M	SD
University ^a	29	3.94	0.57	26	4.15 ^e	0.67	29	3.09	0.77	29	3.53	0.75	29	0.83	0.20
University of applied sciences ^b	39	3.39	1.03	36	3.42	1.16	39	3.10	0.67	39	3.16	0.88	39	0.64	0.28
Higher technical school ^c	39	3.71	1.06	34	3.79	1.15	39	2.94	0.67	39	3.56	0.80	39	0.63	0.29
Matura ^d	19	3.71	0.87	19	3.79	1.08	19	3.01	0.74	19	3.36	0.76	19	0.70	0.28
Apprenticeship ^e	98	3.51	0.93	94	3.33 ^a	0.99	98	3.06	0.71	98	3.37	0.77	98	0.63	0.30
Compulsary school ^f	12	3.69	0.79	10	3.90	0.88	12	2.83	0.64	12	3.45	0.66	12	0.58	0.33
Other ^g	5	3.37	0.69	5	3.60	0.55	5	3.12	0.110	5	3.31	0.50	5	0.80	0.21
Total	241	3.60	0.92	224	3.58	1.04	241	3.03	0.69	241	3.39	0.78	241	0.66	0.29

	ANOVA F(6,234) = 1.474, p = 0.188			ANOVA F(6,217) = 0.720, p = 0.634			ANOVA F(6,234) = 0.584, p = 0.743			ANOVA F(6,234) = 1.045, p = 0.397			ANOVA F(6,234) = 1.757, p = 0.109		
Occupation	n	M	SD	n	M	SD	n	M	SD	n	M	SD	n	M	SD
In training without remuneration	4	4.18	0.74	4	4.50	1.00	4	2.70	0.62	4	3.46	0.27	4	0.88	0.14
In training with remuneration	2	4.23	0.20	2	4.00	1.41	2	2.50	1.84	2	4.07	0.101	2	0.63	0.53
Employed full-time (80-100%)	111	3.63	0.90	103	3.58	1.01	111	3.01	0.70	111	3.42	0.75	111	0.70	0.28
Part-time employed (less than 80%)	53	3.70	0.76	50	3.60	0.90	53	3.05	0.64	53	3.42	0.78	53	0.62	0.30
Full-time housework	11	3.66	1.14	11	3.55	1.13	11	3.11	0.77	11	3.52	0.74	11	0.75	0.27
Currently unemployed	7	3.76	0.77	7	3.71	0.95	7	3.31	0.62	7	3.63	0.65	7	0.75	0.25
Retired	53	3.31	1.07	47	3.45	1.23	53	3.06	0.71	53	3.19	0.88	53	0.58	0.28
Total	241	3.60	0.92	224	3.58	1.04	241	3.03	0.69	241	3.39	0.78	241	0.66	0.29

B-7: Multiple linear regressions – Influence of the independent, continuous variables on specific support, specific acceptance, perceived risks (summative mean), and perceived benefits (summative mean)

Specific support										
	Island					Switzerland				
	F(8.198)= 18.37, p <0.001, R ² =0.403					F(8.187)= 37.12, p<0.001, R ² = 0.597				
Independant variables	b	SD	β	T	Sig.	b	SD	β	T	Sig.
constant	-0.46	0.42		-1.10	0.272	-0.76	0.36		-2.09	0.038
Climate change concern	0.07	0.08	0.07	0.92	0.358	0.23	0.06	0.23	3.82	<0.001
Technological affinity	-0.04	0.09	-0.03	-0.47	0.639	0.09	0.07	0.08	1.30	0.196
Trust in stakeholders	0.62	0.10	0.48	6.46	<0.001	0.22	0.08	0.18	2.94	0.004
Comprehension	-0.04	0.25	-0.01	-0.15	0.879	0.34	0.17	0.10	1.97	0.050
Political attitude	.145	0.07	0.12	2.14	0.034	0.12	0.05	0.18	2.19	0.030
General support	0.31	0.08	0.25	3.72	<.001	0.48	0.07	0.42	7.06	<0.001
General familiarity	-0.02	0.08	-0.01	-0.20	0.845	-0.09	0.06	-0.08	-1.50	0.134

Specific familiarity	0.13	0.08	0.11	1.60	0.112	0.17	0.06	0.15	2.79	0.006
Specific acceptance										
	Island					Switzerland				
	F(8,210)=31.512, p= <0.001, R ² = 0.528					F(8,195)=37.490, p<0.001, R ² = 0.590				
Independant variables	b	SD	β	T	Sig.	b	SD	β	T	Sig.
constant	-0.02	0.31		-.05	0.958	-0.32	0.33		-0.94	0.346
Climate change concern	0.20	0.06	0.23	3.59	<0.001	0.26	0.05	0.29	4.86	<0.001
Technological affinity	0.04	0.07	0.04	0.65	0.512	0.07	0.06	0.06	1.00	0.317
Trust in stakeholders	0.49	0.07	0.45	7.12	<0.001	0.33	0.07	0.29	4.78	<0.001
Comprehension	0.50	0.17	0.14	2.86	0.005	0.28	0.16	0.09	1.79	0.074
Political attitude	0.073	0.05	0.07	1.46	0.146	0.11	0.05	0.11	2.34	0.020
General support	0.12	0.06	0.11	1.96	0.051	0.31	0.06	0.30	5.05	<0.001
General familiarity	-0.04	0.06	-0.04	-0.64	0.522	-0.12	0.06	-0.11	-2.04	0.042
Specific familiarity	0.06	0.06	0.06	0.95	0.343	-0.32	0.33	0.1	-0.94	0.346
Perceived risks (summative mean)										
	Island					Switzerland				
	F(8,210)=2.814, p=0.006, R ² = 0.062					F(8,195)=2.51, p=0.013, R ² = 0.056				
Independant variables	b	SD	β	T	Sig.	b	SD	β	T	Sig.
constant	3.49	0.34		10.22	<0.001	3.09	.35		8.74	<0.001
Climate change concern	0.13	0.06	0.19	2.05	0.042	0.13	0.06	0.20	2.19	0.030
Technological affinity	0.06	0.07	0.07	0.77	0.445	-0.03	0.07	-0.04	-0.38	0.707
Trust in stakeholders	-0.29	0.08	-0.34	-3.83	<0.001	-0.19	0.07	-0.24	-2.59	0.010
Comprehension	-0.05	0.19	-0.02	-0.27	0.785	-0.33	0.17	-0.14	-1.97	0.050
Political attitude	-0.004	0.06	-0.06	-0.07	0.943	0.06	0.05	0.08	1.08	0.281
General support	-0.07	0.07	-0.08	-1.02	0.310	-0.02	0.07	-0.03	-0.38	0.705
General familiarity	0.13	0.07	0.16	1.92	0.056	0.07	0.06	0.09	1.11	0.268
Specific familiarity	-0.05	0.07	-0.06	-0.72	0.472	0.04	0.06	0.05	0.69	0.492
Perceived benefits (summative mean)										
	Island					Switzerland				

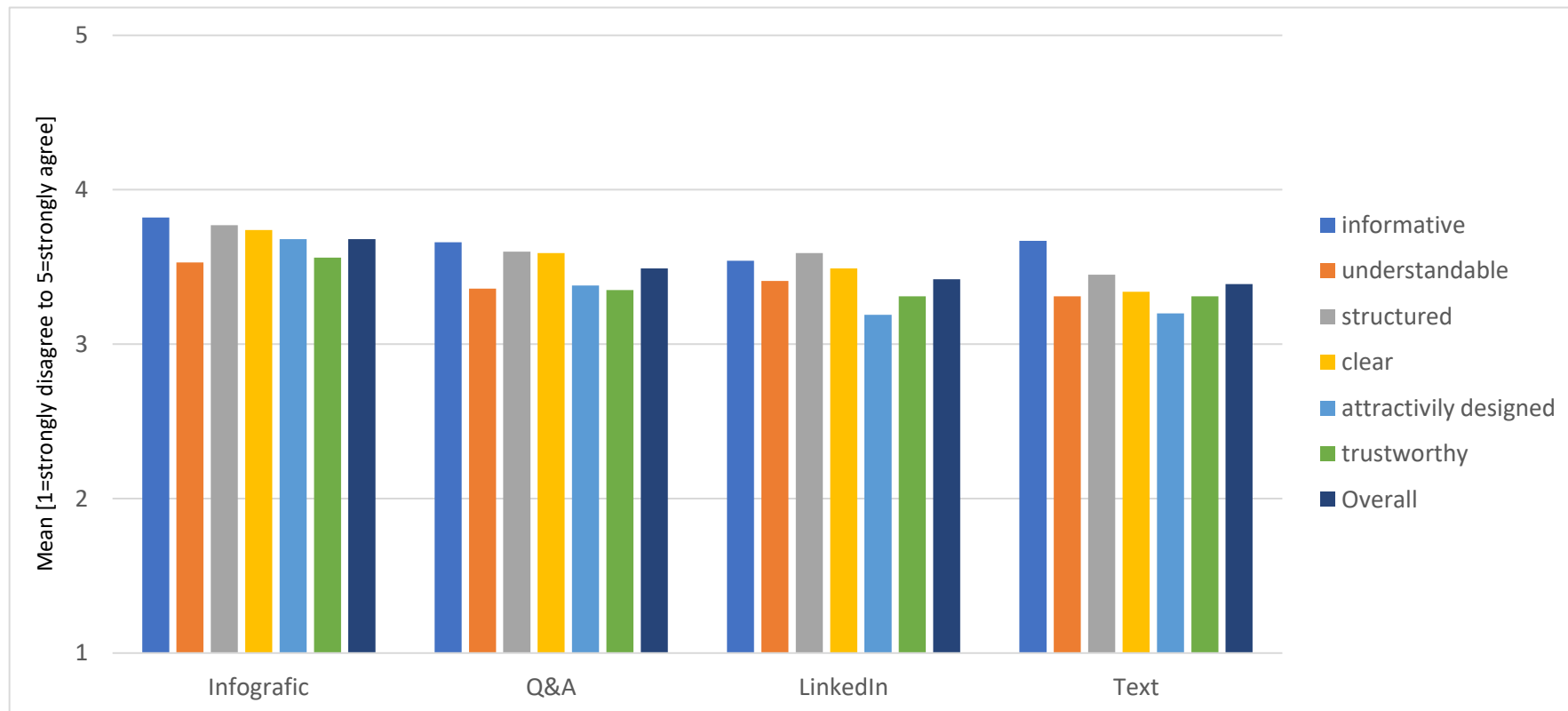
	F(8,210)=19.836, p<0.001, R ² = 0.409					F(8,195)=27.07, p<0.001, R ² = 0.507				
Independant variables	b	SD	β	T	Sig.	b	SD	β	T	Sig.
constant	0.40	0.29		1.41	0.160	0.49	0.30		1.61	0.110
Climate change concern	0.14	0.05	0.19	2.71	0.007	0.05	0.05	0.06	0.96	0.337
Technological affinity	0.03	0.06	0.04	0.53	0.599	0.13	0.06	0.16	2.28	0.024
Trust in stakeholders	0.43	0.06	0.48	6.80	<0.001	0.40	0.06	0.42	6.313	<0.001
Comprehension	-0.12	0.16	-0.04	-0.76	0.447	0.28	0.14	0.10	1.99	0.049
Political attitude	0.16	0.05	0.19	3.53	<0.001	0.07	0.04	0.08	1.55	0.123
General support	0.08	0.06	0.09	1.41	0.161	0.18	0.06	0.21	3.24	0.001
General familiarity	-0.02	0.05	-0.03	-0.44	0.660	-0.03	0.05	-0.03	-0.57	0.571
Specific familiarity	0.02	0.06	0.02	0.28	0.780	0.01	0.05	0.01	0.09	0.926

B-8: One-way ANOVAs – Influence of the eight test versions as well as the four formats on the specific support, specific acceptance, comprehension, and the design perception

Independant Variables	Specific acceptance			Specific support			Comprehension			Design perception		
	ANOVA			ANOVA			ANOVA			ANOVA		
	F(7,4957) = 1.943, p = 0.061			F(7,454) = 1.456, p = 0.181			F(7,495) = 0.965, p = 0.456			F(7,495) = 1.878, p = 0.071		
Testversion	n	M	SD	n	M	SD	n	M	SD	n	M	SD
1 – [Island / Infographic]	75	3.44	0.85	67	3.33	1.02	75	0.66	0.25	75	3.72	0.77
2 – [Island / Q&A]	72	3.58	0.83	69	3.52	0.95	72	0.72	0.24	72	3.59	0.83
3 – [Island / LinkedIn]	62	3.41	0.946	54	3.31	1.16	62	0.67	0.29	62	3.35	0.97
4 – [Island / Text]	53	3.21	1.01	48	3.20	1.22	53	0.64	0.29	53	3.30	0.86
5 – [CH / Infographic]	58	3.65	0.94	55	3.55	1.18	58	0.69	0.26	58	3.64	0.89
6 – [CH / Q&A]	62	3.40	1.06	59	3.42	1.16	62	0.69	0.30	62	3.37	1.02
7 – [CH / LinkedIn]	52	3.74	0.89	45	3.69	0.85	52	0.67	0.30	52	3.50	0.86
8 – [CH / Text]	69	3.63	0.80	65	3.68	0.92	69	0.61	0.29	69	3.45	0.85
Total	503	3.50	0.92	462	3.47	1.07	503	0.69	0.27	503	3.50	0.89
	ANOVA			ANOVA			ANOVA			ANOVA		

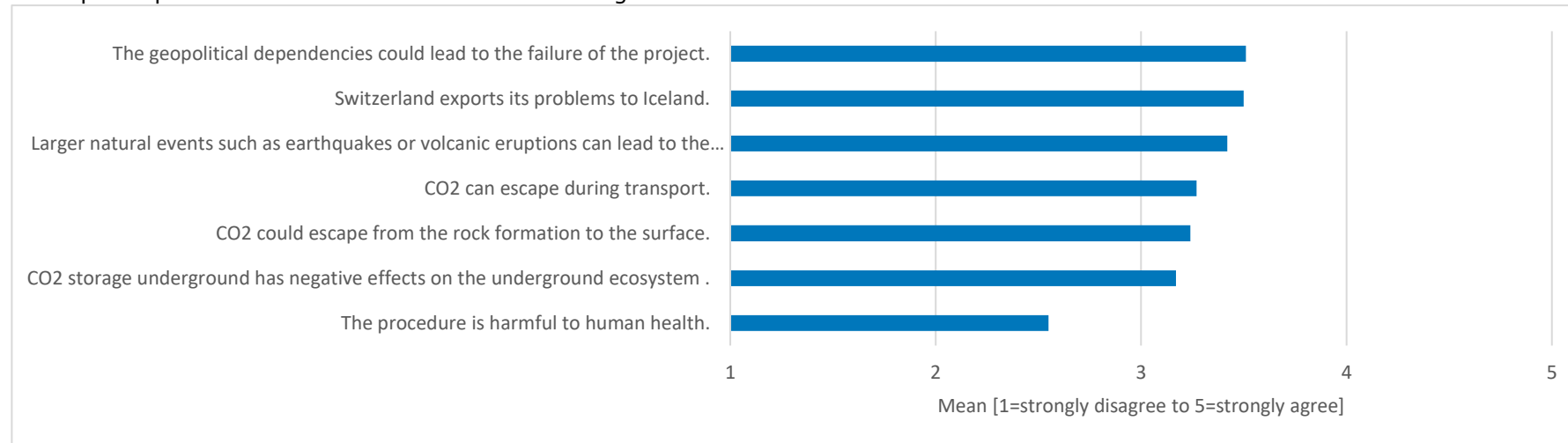
	F(3,499) = 0.460, p = 0.711			F(3,458) = 0.075, p = 0.973			F(3,499) = 1.824, p = 0.142			F(3,499) = 3.006, p = 0.030		
Media	n	M	SD	n	M	SD	n	M	SD	n	M	SD
Infographic ^a	133	3.53	0.89	122	3.43	1.10	133	0.67	0.25	133	3.69^d	0.82
Q&A ^b	134	3.47	0.94	128	3.48	1.05	134	0.71	0.27	134	3.49	0.92
LinkedIn ^c	114	3.56	0.93	99	3.48	1.04	114	0.67	0.29	114	3.42	0.92
Text ^d	122	3.45	0.91	113	3.48	1.08	122	0.63	0.29	122	3.39^a	0.86
Total	503	3.50	0.92	462	3.47	1.07	503	0.67	0.27	503	3.50	0.89

B-9: Design perception

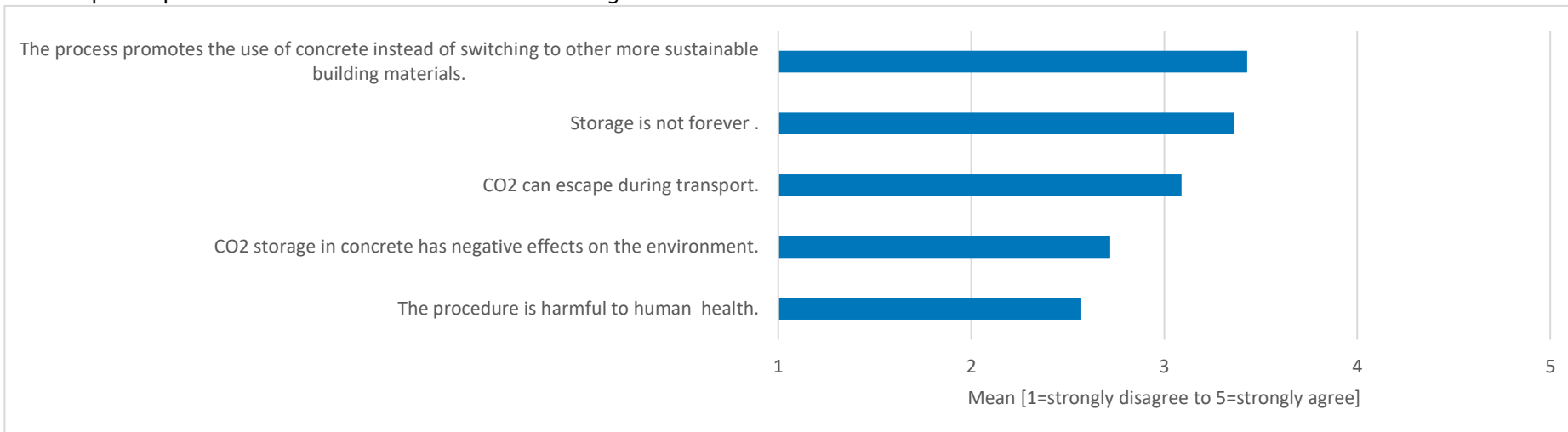


B-10: Perceived risks

Participants' perceived risks in the context of the storage in basalt in Iceland:

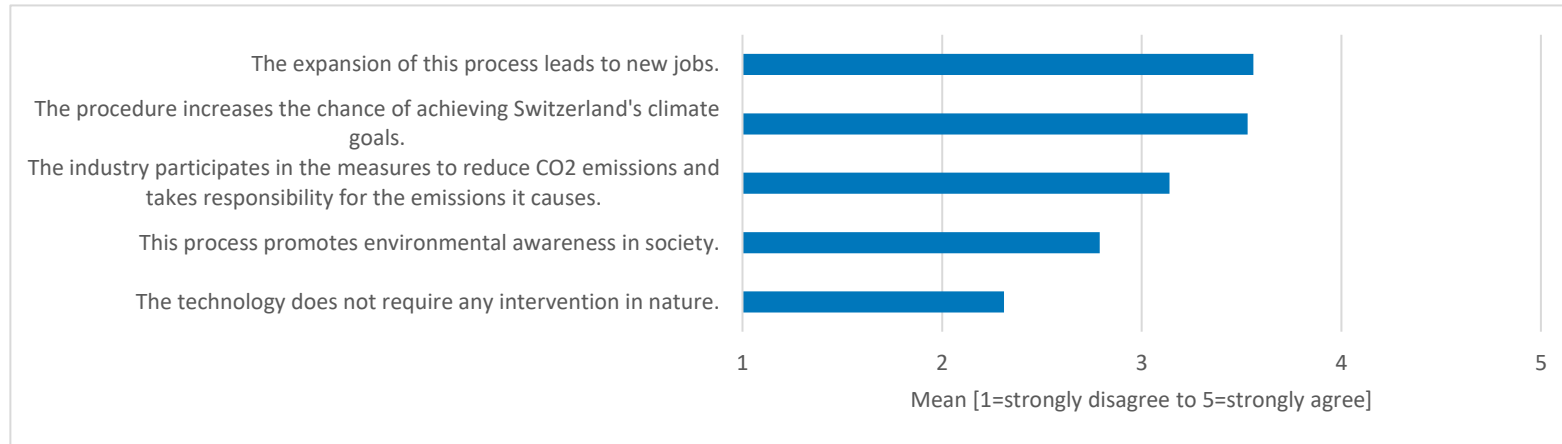


Participants' perceived risks in the context of the storage in concrete in Switzerland:

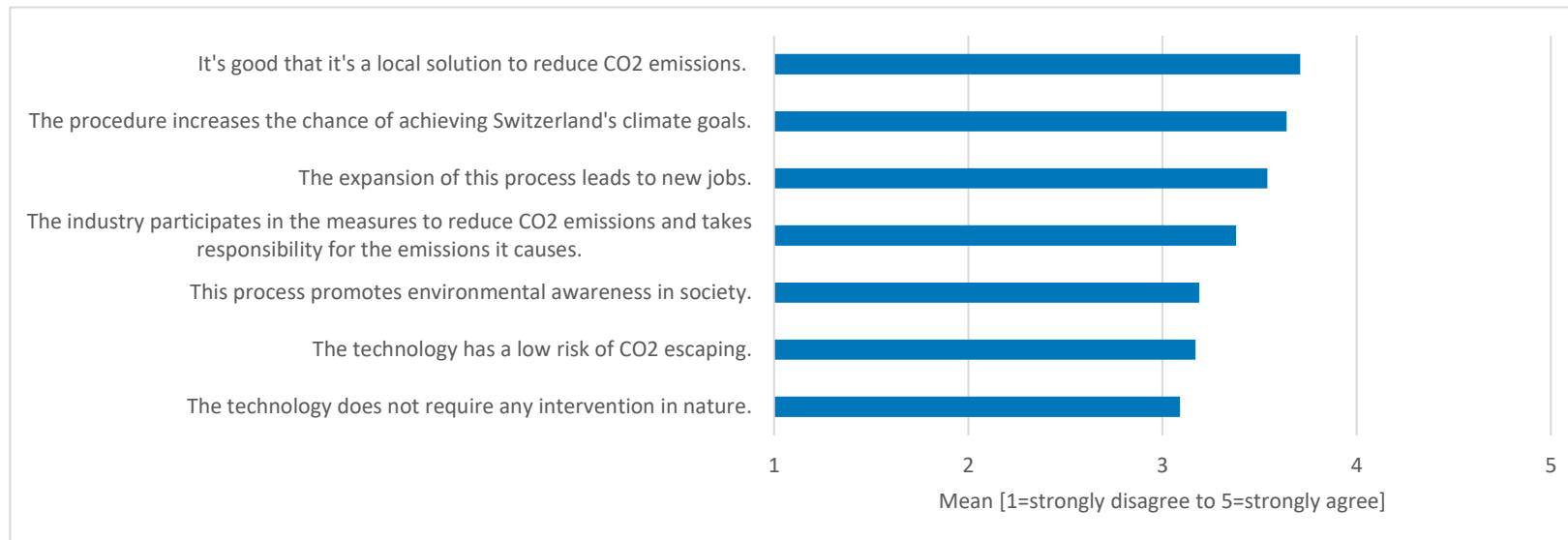


B-11: Perceived benefits

Participants' perceived benefits in the context of the storage in basalt in Island:



Participants' perceived benefits in the context of the storage in concrete in Switzerland:



B-12: Local acceptance index [only Icelandic pathway; n=262]

Multiple linear regression					
	F(8,210)=8.737, p<0.001, R ² = 0.221				
Independent variables	b	SD	β	T	Sig.
constant	0.53	0.47		1.13	0.261
Climate change concern	-0.14	0.08	-0.14	-1.72	0.087
Technological affinity	0.13	0.10	0.10	1.30	0.195
Trust in stakeholders	0.44	0.11	0.34	4.20	<0.001
Comprehension	0.52	0.27	0.12	1.97	0.051
Political attitude	-0.04	0.08	-0.03	-0.53	0.596
General support	0.25	0.09	0.20	2.64	0.009
General familiarity	0.10	0.09	0.08	1.07	0.287
Specific familiarity	-0.05	0.09	-0.04	-0.54	0.589

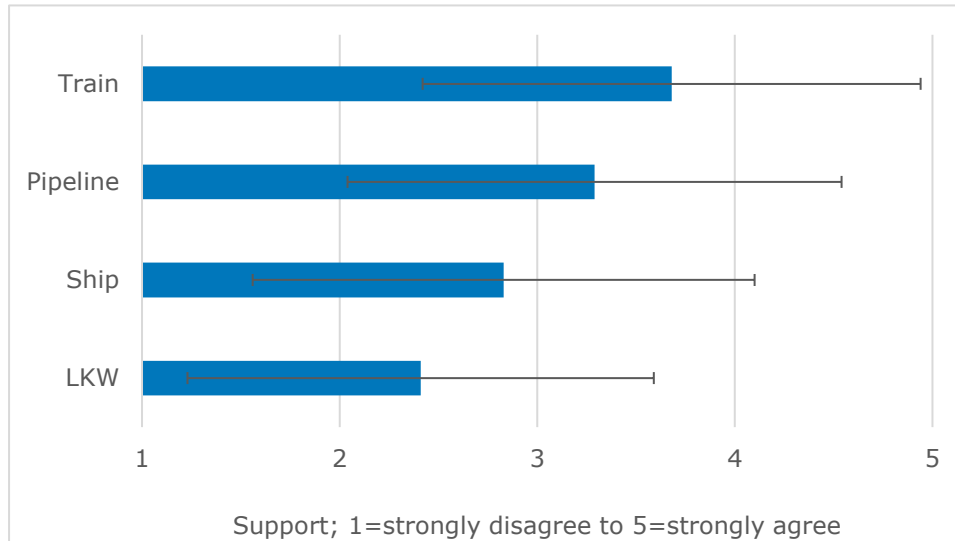
One-way ANOVA			
F(4,257) =0.371, p= 0.829			
Age category	n	M	SD
18-30	55	3.06	0.10
31-42	51	2.89	0.99
43-54	48	3.06	1.00
55-66	52	2.98	1.20
67-100	56	3.12	1.18
Total	262	3.02	1.08
One-way ANOVA			
F(21,240)=0.827, p=0.686			
Living canton	n	M	SD
Aargau	20	3.19	1.36
Appenzell Innerrhoden	1	2.50	.

Appenzell Ausserrhoden	2	2.88	0.18
Bern	51	3.00	1.15
Basel-Country	13	2.961	0.92
Basel-City	3	3.58	0.52
Fribourg	3	4.67	0.14
Geneva	0	-	-
Glarus	1	3.25	.
Graubünden	12	2.92	0.93
Jura	0	-	-
Lucerne	15	2.60	0.78
Neuchâtel	0		
Nidwalden	5	3.20	0.81
Obwalden	0	-	-
St. Gallen	19	2.95	1.27
Schaffhausen	5	3.45	1.28
Solothurn	7	3.54	0.65
Schwyz	2	2.37	1.94
Thurgau	18	2.90	1.10
Ticino	3	2.92	0.63
Uri	2	3.38	0.53
Vaud	1	2.75	.
Valais	1	2.00	.
Zug	2	4.00	0.35
Zurich	76	2.99	1.06
Total	262	3.02	1.08
ANOVA			
F(1,257)=13.604, p < .001			
Gender	n	M	SD
female	136	2.78	0.98
male	123	3.26	1.11
Total	259	3.00	1.07

ANOVA			
F(6.255)=1.386, p=0.221			
Education	n	M	SD
University	36	3.15	1.07
University of applied sciences	30	3.28	1.04
Higher technical school	40	3.12	0.99
Matura	43	3.03	1.10
Apprenticeship	104	2.82	1.09
Compulsary school	8	3.50	1.09
Other	1	3.75	.
Total	262	3.02	1.08
ANOVA			
F(6.255) =1.049, p=0.394			
Occupation	n	M	SD
In training without remuneration	11	3.59	0.70
In training with remuneration	5	2.60	1.15
Employed full-time (80-100%)	108	3.07	1.04
Part-time employed (less than 80%)	52	2.82	1.01
Full-time housework	11	3.02	1.38
Currently unemployed	13	2.86	1.07
Retired	62	3.07	1.17
Total	262	3.02	1.08

B-13: Evaluation of transportation means

How much do people prefer different transportation means for CO₂?



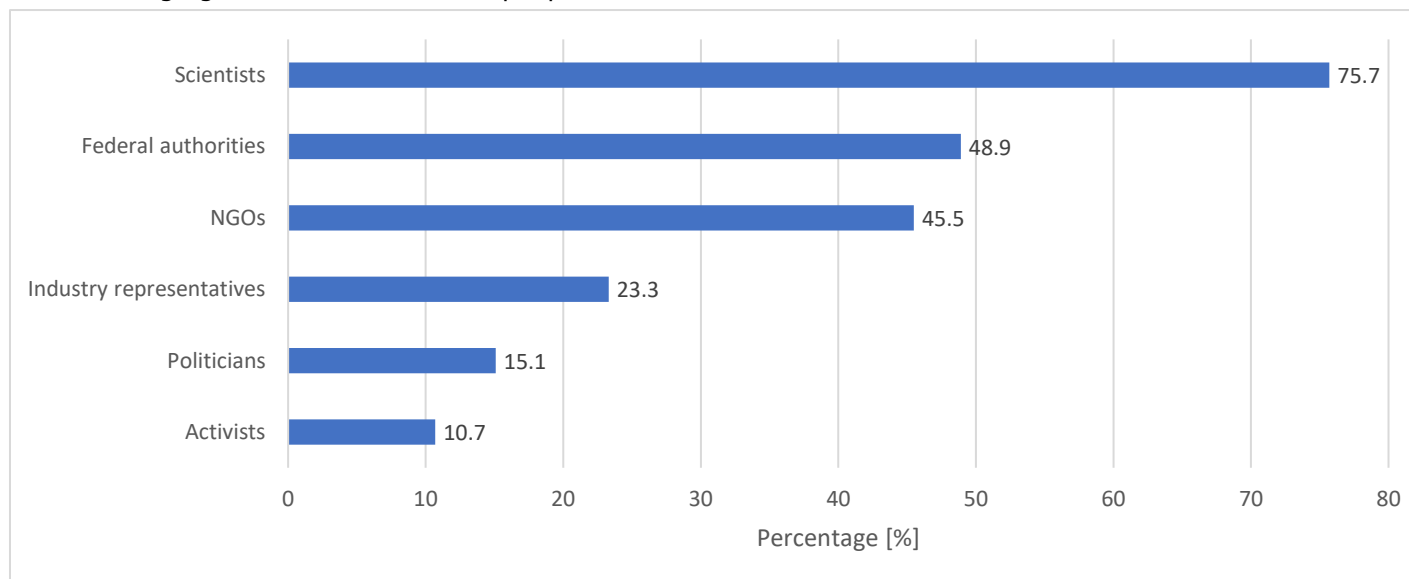
B-14: Evaluation of the origin of CO₂

We asked the participants to evaluate if they would support the CO₂ storage in Switzerland more or less depending on the origin of the CO₂:

I support the storage of CO2 in Switzerland, if ...	Mean	SD
The CO2 comes from outside Europe	1.98	1.17
I don't know where the CO2 comes from	2.02	1.27
The CO2 comes from Europe	2.47	1.21
The CO2 comes from neighbouring countries of Switzerland	2.69	1.25
The CO2 comes from Switzerland	3.94	1.08

B-15: Communication preferences

The following figure shows from whom people want to receive information on CCTS/CCUS:



B-16: Comparison of the benefits from the literature, focus groups, and public survey

In the following table we compare the benefits that were identified by previous studies with those assessed in our focus groups and public survey. Red highlighted are the benefits which we additionally to previous studies identified.

Perceived benefits		Sources	Focus groups	Public survey
Social benefits	Part of a broader strategy to reduce CO2 emissions and mitigate climate change	(Oltra et al., 2010)	X	
	Trigger to increase society's environmental awareness		X	X
	Solution also for other countries		X	
	Industry helps and takes responsibility		X	X
	Politically easier to get accepted (no personal reduction needed)		X	

Environmental benefits	Reduction of CO2 emissions	(Oltra et al., 2010)	X	X
	Effective in combating climate change/ impacts of global warming	(Li et al., 2017; Perdan et al., 2017)		
	Improvement of air quality at location	(Perdan et al., 2017)		
	Reduction of water pollution at location	(Perdan et al., 2017)		
	Addressing climate severity and urgency	(Satterfield et al., 2023)		
	Unavoidable CO2 emissions can be captured and stored		X	
	Contributes to the chance to reach the net-zero goals		X	X
Economic benefits	Reuse of CO2	(Oltra et al., 2010)		
	Exploitation of carbon reservoirs	(Oltra et al., 2010)		
	Benefits for local communities (e.g., jobs)	(Oltra et al., 2010; Perdan et al., 2017)		X
	Reduced electricity price or transport fuel price	(Perdan et al., 2017)		
Technological benefits	Bridging technology while renewable energies are deployed	(Oltra et al., 2010)		
	Achievement of current energy demand	(Oltra et al., 2010)		
	Long-term storage of CO2		X	

B-17: Comparison of the risks from the literature, focus groups, and public survey

In the following table we compare the risks that were identified by previous studies with those assessed in our focus groups and public survey. Red highlighted are the risks which we additionally to previous studies identified.

	Perceived risks	Sources	Focus groups	Public survey
Social risks	Impact on human health	(Arning et al., 2019; Oltra et al., 2010)	X	[not]
	Health risk of workers at the storage site	(Li et al., 2017)	X	
	Opposition of local population (to import foreign CO2)	(Merk et al., 2022; Oltra et al., 2010)	X	
	Opposition of local environment NGOs	(Oltra et al., 2010)		
	Fear of waste dump to poor countries / exporting own problems (ethical question)	(Oltra et al., 2010)	X	X
	Storage similar perceived as radioactive waste storage	(Oltra et al., 2010)		
	Dependency on other countries (e.g., transportation through other countries)	(Nick & Thalmann, 2021)	X	X
	NIMBY (Not in My Backyard) phenomenon	(Li et al., 2017)		X

	Reduction of awareness of the CO2 emission problems	(Oltra et al., 2010)		
	Political lobbying because may accept it (do not have to change their lifestyle)		X	
	Inertia of the political system (everything takes too long, thus we will not achieve the goals until 2050)		X	
	No incentive to emit less CO2 (sufficiency; decarbonization)		X	
	Large natural events such as earthquakes or volcanic eruptions can lead to CO2 leakage.			X
Environmental risks	Negative impacts on the ecosystem/environment (e.g., pollution)	(Arning et al., 2019; Li et al., 2017; Oltra et al., 2010; Wallquist, 2011)	X	X
	Altering nature	(Oltra et al., 2010)		
	Groundwater pollution	(Li, Liu, Cai, et al., 2017; Wallquist, 2011)	X	
	Impact on marine environment	(Li et al., 2017)		
	Induced earthquakes/ volcanic eruptions	(Wallquist, 2011)	X	
	Soild acidification	(Wallquist, 2011)		
	Rapid release of a big amount of CO2 (effect on global climate)	(Li et al., 2017)		
	High energy consumption to capture, compress and transport CO2 at large scale and build infrastructure	(Li et al., 2017; Nick & Thalmann, 2021)	X	
	Neglection of environmental justice	von Rothkirch and Ejderyan (2021)		
	Uncertainties and unknown impacts in the future	(Oltra et al., 2010; Wallquist, 2011)		
	Not solving the problem of emissions	(Oltra et al., 2010)		
	CCTS/CCUS only removes CO2 and no other pollutants such as PM25, sulphur dioxide, benzene, ozone, nitrogen oxides, carbon monoxide	(Nick & Thalmann, 2021)		
Economic risks	Incentive to further use fossil fuels	(Oltra et al., 2010; Satterfield et al., 2023)		
	High investment costs	(Nick & Thalmann, 2021; Oltra et al., 2010)		
	High costs (for building, maintaining and retrofitting pipelines)	(Nick & Thalmann, 2021)	X	
	Construction industry has no incentive to reduce CO2 footprint		X	
	Neglection of sustainable substitutes		X	X
	Wrong investment, i.e. financial resources needed for other measures		X	
Technological risks	Leakage releases (due to e.g. failures, accidents, undetected faults)	(Oltra et al., 2010; Satterfield et al., 2023; Wallquist, 2011)	X	X
	Unproven technology	(Oltra et al., 2010)		
	Explosions during transportation/storage procedure	(Oltra et al., 2010)		
	Capacity limits to store CO2	(Oltra et al., 2010)	X	
	Limited efficacy of technologies	(Oltra et al., 2010)		

Perceived uncontrollability	(Arning et al., 2020)
Transportation pipelines impact on environment, ground landscape	(Li et al., 2017)
NOT long-term storage	X



Zurich, 15 December 2023

Deliverable 5.8: Technical regulatory gaps for the pipeline

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1 Introduction

1.1 Background and objectives

This report addresses technical questions regarding the transport infrastructure necessary for large-scale deployment of CCTS and CCUS: specifically, existing gaps in the technical regulatory framework for the design, construction and operation of a CO₂ pipeline.

Overall, the technical regulatory framework for CO₂ pipelines in Switzerland is very limited. So far, no specific laws, regulations, or standards have been proposed for the design, construction, or operation of CO₂ pipelines. Existing CO₂-specific regulations focus on the reduction of CO₂ emissions but do not address technical pipeline-related aspects [1]. The revised CO₂ Act, rejected in the June 13, 2021 public vote and subsequently revised again by the Federal Council, does not contain any technical provisions regarding CO₂ pipeline construction and operation, but instead focuses on incentive systems supplemented by targeted subsidies and investments [2]. Further, there is no constitutional basis for comprehensive legislation and technical regulation of CO₂ pipelines at the federal level. As of today, the competence regarding this lies with the cantons [3, 4].

At the same time, Switzerland already has technical regulations in place that could possibly be relevant for CO₂ pipelines: firstly, existing pipeline-specific technical regulations, namely for the transport of oil and gas. Second, technical regulations have been established which typically must be considered for the design, construction, or operation of larger infrastructure projects – for example, regarding spatial planning or environmental protection. A simple extension of the scope of this existing technical regulatory framework to CO₂ pipelines is not permitted due to the lack of federal competence and would probably not properly address the specific properties of CO₂ and its pipeline transport. Still, the existing technical regulatory framework could serve as a reasonable starting point or, to some extent, even be transferrable to a CO₂-specific pipeline regulatory regime. In addition, there are several international standards that could serve as a basis for developing technical regulations for CO₂ pipelines. Several countries have already started to develop their own national technical regulations for CO₂ pipelines and could therefore provide potentially useful examples of how a technical framework specifically for CO₂ pipelines can be developed in line with existing legislation.

The main objectives of this subtask are twofold: first, the identification of key technical aspects for the development of a regulatory framework for CO₂ pipelines. The selection of these key technical aspects is based mainly on the first conceptual study for a CO₂ pipeline collection network in Switzerland that was conducted by the Italian pipeline engineering company Saipem and led by the Swiss Association of Waste Treatment Plant Operators (VBSA). Second, an overview of possible options and next steps for how these technical regulatory aspects could be developed is provided. This is based on an investigation into relevant existing and developing practices in and outside of Switzerland. A high-level overview of existing technical regulatory frameworks for CO₂ pipelines outside of Switzerland and approaches that have been applied for initial projects aims to ensure that the regulatory perspectives include supra-national aspects relevant to the connection of a Swiss CO₂ pipeline to a larger, possibly European-wide, network. Overall, the aim of the report is to provide a first assessment of the technical regulatory framework in Switzerland possibly relevant for CO₂ pipelines and therefore lay the groundwork for the planning of the next steps to develop a CO₂-specific technical regulatory framework.

1.2 Scope and methodology

In the context of this report, the term ‘technical’ refers to the mechanical and environmental aspects of design, construction, and operation of a CO₂ pipeline rather than financial and organizational aspects (which are addressed in DemoUpCARMA WP5, Subtask 3.3 – *Organizational and financial models for future CO₂ infrastructure*). The term ‘regulatory aspects’ encompasses laws and regulations as well as national and international standards. Lastly, the focus is on CO₂ pipelines in Switzerland rather than CO₂ capture units or storage sites.

- i. As a starting point, general competences for the development of legislation and technical regulations for CO₂ pipelines are investigated. This is due to their importance in providing a certain framework and boundary conditions for more detailed development of actual laws and regulations (see section 2). Options for advancing the authoritative framework for CO₂-specific regulation are discussed.



- ii. Second, key technical regulatory aspects and assumptions that emerged from the pipeline study and from consultations with relevant stakeholders are identified and described (see section 3).
- iii. Third, given the rather country-specific design of technical regulatory frameworks, existing technical regulations for other pipelines in Switzerland, namely oil and gas pipelines, and more general technical regulations which typically must be considered for the design, construction, or operation of larger infrastructure projects, are analysed (see section 4).
- iv. Lastly, existing international standards as well as current and developing technical regulatory frameworks for CO₂ pipelines in selected countries are investigated. These countries have been identified as the most relevant cases for consideration due to their state of progress and the availability of accessible information at the time of conducting this research (see section 5).

The findings and the key open issues that require future research are summarized. Due to the novelty of this topic and the scarcity of existing technical regulations for CO₂ pipelines, the work and outcome of this subtask are mainly geared at providing a first overview of technical regulatory aspects to focus on for CO₂ pipeline networks in Switzerland and serves as a starting point for further in-depth analysis to provide conclusive recommendations.

2 Competences and authority for CO₂ pipeline regulation in Switzerland

This section analyses the general competences and authority for the development of legislation and technical regulations for CO₂ pipelines in Switzerland. The aim is to provide an overview of the current framework upon which a technical regulatory regime for CO₂ pipelines could be developed. Three potential pathways to establishing the legislative authority for CO₂ pipeline regulation are presented and examined, along with a relevant case study for the most novel approach.

2.1 Current status

In general, the Federal Constitution defines that the cantons are responsible for legislation and regulations unless explicitly stated otherwise in a federal law [3]. The most proximate federal law to the CO₂ pipeline case is that of the transport of energy, for which the Federal Constitution designates the Confederation as responsible for legislation on the transport of electricity, and the pipelines for the transport of liquid or gaseous fuels [5]. The Constitution thus only provides the basis for the development of legislation on energy technologies at the federal level – for example, regulations on oil and gas pipelines. However, an extension of the existing oil and gas pipeline legislation to CO₂ pipelines, as has been successfully implemented for hydrogen pipelines as of 2023 in accordance with the Pipeline Ordinance, is not permissible. The law only covers fuels, whereas CO₂ is only a combustible for heat generation. This mere characteristic as an energy carrier is not sufficient to be covered by this law, according to the unanimous opinion so far. Thus, at the federal level, there is no constitutional basis for comprehensive technical regulation of CO₂ pipelines. This was confirmed in workshops with relevant stakeholders and during a conference organized by the FOEN [6, 7]. This leaves the government with three different options on how to approach the development of legislation and technical regulations for CO₂ pipelines.

2.2 Competence remains with the cantons

The first identified option is one that adopts the current legislative framework, which indicates that the competence to regulate CO₂ pipelines lies with the cantons. In this case, the key challenge becomes the coordination among the different cantons – the currently foreseen routing of the Saipem study passes nine cantons (Aargau, Basel, Bern, Fribourg, Solothurn, St. Gallen, Valais, Vaud, Zurich) [8]. Requirements for the planning approval procedure of the project, as well as the exact pipeline routing, technical regulations, or environmental impact assessments (EIA), would likely have to be agreed upon separately with all affected cantons and Federal Offices.

Overall, it is challenging to assess the complexity and needed resources in the case that competences regarding the regulation of CO₂ pipelines remain with the cantons – in the past, no comparable large



infrastructure projects can be referenced that were regulated on the cantonal level. In view of the size and complexity of the project, however, it can be assumed that the regulation by the cantons seems unfeasible in the medium to long term. In the short term, the construction of a first section in one canton, for example Basel, may be feasible, since the coordination effort would be omitted for the time being. This first step could be undertaken more or less immediately, since no legislative amendments would be needed.

2.3 Competence is given to a (new) federal authority

For comprehensive regulation of CO₂ pipelines at the federal level, a new constitutional basis would be needed. In general, an amendment to the Constitution can be proposed by a popular initiative, the Federal Council, the National Council, the Council of States, or a canton [9, 10]. For the present case, it is assumed that the amendment would be initiated by the Federal Council, which would first prepare a draft for the amendment of the Constitution. This draft would then be discussed by the Councils in the ordinary legislative procedure and subsequently put to public vote and the vote of the cantons [11, 12]. The following timelines on ordinary legislative procedures can be used as a reference for the time required for an amendment of the Constitution, from initiation to enactment: half of the legislative procedures take 33 months or less, with the average taking 51 months. Of this time, around two-thirds is spent on preparation by the Federal Council and administration, and the rest on consultations in Parliament and the post-Parliamentary phase [13]. Provided that the amendment is accepted by the public vote and the vote of the cantons, it is enacted, therefore giving the federal government a constitutional basis for comprehensive technical regulation of CO₂ pipelines.

Overall, an amendment to the Constitution seems to be the most appropriate solution for the size and complexity of the foreseen CO₂ pipeline project in Switzerland, but also with regards to the technical regulatory framework that needs to be developed for it. Furthermore, this option would also provide the federal government with the greatest flexibility. With this competence, the Federal Council would be free to either extend the existing oil and gas pipeline legislation to include CO₂ pipelines, or to develop new laws and regulations specifically for CO₂ pipelines. At the same time, it should be noted that this process is likely to take the longest time compared to the other two options.

2.4 Application of Article 81 of the Federal Constitution

A more unconventional option is the application of Article 81 of the Federal Constitution. Article 81 was explicitly established for larger (infrastructure) projects that the cantons could not implement on their own or that go beyond their interest [14]. Due to an increasing expansion of federal competences in the infrastructure sector, the relevance of Article 81 has steadily declined in the last century. Article 81 states that “the Confederation may in the interests of the country as a whole or a large part of it carry out and operate public construction works, or provide support for such construction works” [15]. The provision distinguishes two setups: the first setup concerns the design, construction, and operation of public infrastructure by the federal government. The second setup concerns the support of the construction of public infrastructure by the federal government. Consequently, the federal government does not necessarily have to own or operate the infrastructure itself – however, if it only has the supporting role, its involvement must be limited to the construction phase [16]. According to a more traditional view, Article 81 does not provide the federal government with any legislative competence, but rather a direct administrative competence. In practice, however, there are several projects for which a legislative competence was also provided. In this case, federal legislation based on Article 81 must be limited to a specific project and directed at the essentials of the project. In contrast, a more extensive general legislation for a specific category of works would clearly go beyond the scope of Article 81. In this case, a specific subject competence would be required at the constitutional level [16].

Overall, the application of Article 81 of the Constitution is likely the option with the most uncertainties and for which the most clarifications would have to be undertaken. A recent example for legislation at the federal level through the application of Article 81 is the federal law on the underground transport of goods (“*Bundesgesetz über den unterirdischen Gütertransport*”) in the context of the Cargo Sous Terrain project (for details, see section 2.4.1). However, whether and to what extent the procedure for the Cargo Sous Terrain (CST) project represents a direct blueprint for the case of CO₂ pipelines is uncertain, even though CST quoted the Federal Office of Justice (FOJ) on stating that a similar process could be envisioned for a CO₂ pipeline project. In this regard, it may be viable to investigate whether the Parliament could be approached with a concrete project plan, including a proposal for the routing, with



the final goal to work out a legal framework simplifying the plan approval procedure. Analogue to the federal law, which was passed for CST, the SFOE could potentially be envisioned as the approval authority [7]. The possibility of following this approach was also discussed in the workshop with the FOE section 'networks' [6].

2.4.1 Cargo Sous Terrain project

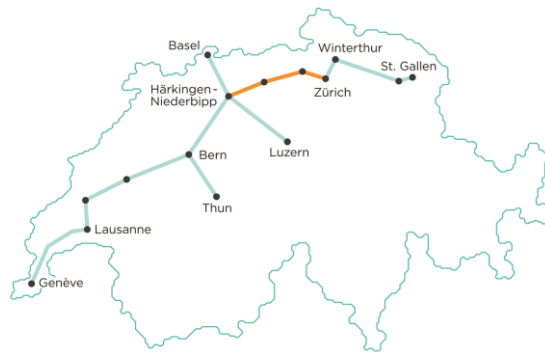


Figure 1: Planned CST network.

CST is a logistics system project for the transport of goods which connects production and logistics sites with urban centres. Underground, goods are planned to be transported in tunnels, whereas above ground, it is foreseen to distribute them in environmentally friendly vehicles. The first section of around 70 kilometres will connect Härkingen-Niederbipp with Zürich and is expected to be built by 2031. The total network with a length of around 500 kilometres between Lake Constance and Lake Geneva, with branches to Basel, Lucerne and Thun, is expected to be finalized by 2045 (see Figure 1) [17].

Initially, CST faced the same key challenge as the current CO₂ pipeline case: The Constitution did not provide any basis for the development of legislation at the federal government level. Conclusively, CST would need to coordinate among the different affected cantons and Federal Offices for the design and construction of their logistics system, including the requirements for the planning approval procedure of the project. In 2015, CST approached the federal government with a concept for the project and the request to examine whether the federal government could support CST with a uniform planning approval procedure at the federal level to ensure a uniform phased planning, design, and construction. This request was supported by the feasibility study prepared by CST, which indicated that a federal-level planning approval procedure is a critical prerequisite for the successful realization of the project since it would significantly reduce the lead time and therefore increase the attractiveness for investors, thus secure financing [18].

In November 2016, the Federal Council first discussed the project and – due to expected economic benefits for the public sector and the general public, such as the reduction of traffic congestion and greenhouse gas emissions – considered the application of Article 81 of the Federal Constitution [15]. It was agreed to support CST with a special federal law with the purpose to create a single legal basis instead of cantonal and municipal regulations for the construction and operation of the entire project, therefore making it easier for project developers to move forward with the planning and approval phase. Furthermore, it was confirmed that the federal government will not support the project financially. The support by the Federal Council for the enactment of a special law was tied to several conditions [19]:

- CST will be transformed into a stock company.
- The project sponsors guarantee sufficient financial resources in the amount of at least CHF 100 million, with at least 50% contributed by Swiss investors.
- The future operators must make binding commitments, namely on the necessary steps to reorganize the logistics and transport chain in the affected areas.
- The cantons of Zurich, Aargau, and Solothurn, which are affected by the first section of the CST network, must agree to the implementation, and include the project in their regional transport planning.
- Access to the CST system must be granted on a non-discriminatory basis.

In April 2019, the Federal Council opened a consultation procedure on the project. In general, a consultation procedure aimed to involve the cantons, political parties and interested groups in the formation of opinions and decision-making by the Confederation. It was intended to provide information on the factual correctness, suitability for implementation and acceptance of a foreseen project [20]. The specific consultation for project CST was intended to show whether the project in general and the creation of a special federal law for it is supported by the main political and economic players and if CST



fulfilled the conditions defined in 2016. After the closing of the consultation around three months later, the Federal Council decided to further support the creation of a special federal law and to submit a draft law to the Federal Assembly [18].

In October 2020, the Federal Council submitted a law to the Parliament that regulates the conditions under which the project can be approved and implemented. The foreseen approval procedure is largely based on the Swiss railway law. In September 2021, the federal law on the underground transport of goods (*“Bundesgesetz über den unterirdischen Gütertransport”*) was passed by the Parliament. After the settlement of the last differences, in December 2021, the Parliament approved the law in a final vote, based on Article 81 and Article 87 (railways and other modes of transport) of the Constitution, thus giving the CST project implementation a single legal basis [21].

In summary, the law regulates the construction and operation of inter-cantonal facilities for the underground transport of goods and the operation of vehicles on these facilities. The approval authority is the Federal Office of Transport (FOT). The FOT monitors compliance with the provisions of the law in the construction, operation, and maintenance of the network as well as compliance with safety-related regulations. As for the plan approval procedure, a proposal for the routing including the potential for conflict and optimization regarding the use of the space, the existing traffic facilities and the environment must be submitted to the FOT at an early stage. Upon the assessment and proposal of the FOT, the Federal Council shall then decide whether to designate the areas suitable for the planned network in a sectoral plan. If it designates the suitable areas in a sectoral plan, the cantons shall determine the areas for the installations and the routing of the network in their structure plans. The Federal Council may set deadlines for the cantons to make these determinations. The concerns of the affected cantons regarding the routing must be adequately considered in the planning and construction. If a canton fails to determine the exact routing within the set time limit, the Federal Council may do so. Furthermore, CST may be required to propose at least two variants for the routing of the network. All permits required under federal law are granted within this plan approval procedure. In general, cantonal concessions and permits are not required, with cantonal law to be considered insofar as it does not unreasonably restrict CST in its activities [22].

As a result, CST adjusted its structures to meet the requirements of the legal planning and approval process. The main investors contributed the CHF 100 million that had been contractually committed for some time to advance the planning of the overall logistics system to the point where it is ready for construction approval. Planning of the first section from Härkingen-Niederbipp to Zurich is expected to be completed by 2025. This involves close coordination with the cantons and municipalities involved as part of the sectoral plan and the structure plan procedures to ensure the participation of all bodies. Construction of the first section is expected to begin in 2026 [23].

The application of Article 81 of the Federal Constitution to CTS and the legal and economic procedures that followed are unique to this case. However, the key developments that allowed the CTS project to utilize this legal basis may provide insight into how a similar application could be possible for a Swiss CO₂ pipeline, and under what conditions.

3 Key technical regulatory aspects

This section describes the key technical regulatory aspects and assumptions that emerged from the Saipem pipeline study, supplemented by aspects that were identified during consultations with relevant stakeholders. The starting point for the selection of regulatory topics to be further explored in this report is narrowed in two ways: first, the focus is on CO₂ pipelines in Switzerland, excluding capture units and storage sites. Second, the analysis is confined to technical regulations rather than financial or organizational aspects. The aim is to identify the technical and environmental aspects for which regulatory clarity is likely crucial to the implementation of a CO₂ pipeline, which will then guide the assessment of the existing regulatory landscape and the recognition of potential legislative hurdles.

3.1 Background

The pipeline study's main goal was to assess the financing needs of constructing and operating a large-scale CO₂ pipeline network in Switzerland. In the scope of the study, 32 emitters from hard-to-



decarbonize industries in Switzerland, such as waste-to-energy, cement or chemical, with emission rates above 100,000 tons of CO₂ per year were considered. Five pipeline scenarios were explored, which differ regarding the exact routes and applied operating pressure levels [24].

In addition, the study aimed to better understand the technical feasibility of such a pipeline network. However, these technical assumptions of the study were solely based on desk research assessment and the input data was taken from publicly available information. Throughout the report and during discussions with Saipem for their operational expertise on the design, construction, and operation of such a pipeline network, it was made clear that additional quantitative risk assessments, environmental and social impact assessments, as well as the involvement of local authorities, will be key for the further planning and the design of the pipeline. Also, it was recommended to share the outcomes resulting from the quantitative risk assessments and environmental and social impact assessments with local authorities in advance and during the planning approval procedure and to freeze the pipeline routing before the detailed design phase [24].

3.2 Identification of key technical aspects

In principle, the technical assumptions of the study were not based on Swiss regulations, but on international standards (for details on international standards, see section 4). Primarily, the study used the following ISO standard as a reference design standard [24]:

- ISO 27913:2016: Carbon dioxide capture, transportation, and geological storage – Pipeline transportation systems” as a reference design standard

Further, the following standards were considered in case of some supplemental requirements [24]:

- ISO 13623:2017: Petroleum and natural gas industries – Pipeline transportation systems
- DNV-RP-F104: Design and operation of carbon dioxide pipelines
- API Specification 5L, 46th Edition: Line pipe

Overall, the study provides a reasonable starting point regarding technical aspects for CO₂ pipelines, however, it does not specifically assess these aspects from a regulatory perspective. As a result, key technical aspects and assumptions that emerged from the study are identified and summarized in the following to provide a basis for further investigation of the regulatory perspective thereof. After a pre-selection based on the study, the final selection of the relevant technical and environmental aspects was discussed in a workshop with the Swiss Federal Office of Energy (SFOE) section ‘networks’ [6]. After this workshop and based on further consultation with the SFOE and the Federal Office for the Environment (FOEN), additional relevant environmental aspects were added (see Table 1).

Table 1: Identified key technical regulatory aspects and assumptions.

CO ₂ stream composition	In general, a typical CO ₂ stream composition from a post-combustion capture process is assumed. The maximum water content for the fluid entering the pipeline system of 30 ppmv to avoid corrosion issues, water drop out or hydrate formation was based on the Northern Lights project CO ₂ specifications. Furthermore, the maximum allowable content of other impurities was based on ISO 27913, which specifies additional requirements and recommendations not covered in existing pipeline standards for the transport of CO ₂ [25].
Crossings	The study emphasizes that construction at crossings is subject to special approval by the responsible authorities and must comply with statutory and technical regulations as well as state-of-the-art pipeline construction practices. Crossings through urban areas may need to consider lower pressure and/or larger safety distances. In general, crossings are deemed a key point for ensuring safe and reliable routing [8].
Environmental impact assessment (EIA)	The study points out the need for an EIA to be performed at a later stage. At the same time, several aspects of the project are identified which potentially pose severe environmental impact challenges, above all the routing [8].



Expropriation	This aspect was added after consultation with relevant stakeholders.
Major accidents	This aspect was added after consultation with relevant stakeholders.
Maximum operating pressures	In general, two maximum operating pressure options for the transport are considered. Gas phase transport with a maximum operating pressure of 40 barg and dense phase transport with a maximum operating pressure of 150 barg. Further, due to safety reasons, pipelines crossing urban areas are considered to operate at a maximum pressure of 10 barg [8].
Planning approval procedure	This aspect was added after consultation with relevant stakeholders.
Safety distances	The study routing paid particular attention to human presence and aimed to keep the distances necessary for the safe construction and operation of the pipeline system and the protection of the environment and the public, i.e., from existing houses, buildings, and existing private and public property. In accordance with ISO 13623, safety zones were defined along the pipeline routing. Furthermore, the study pointed out that hazardous distances for CO ₂ may be considerably longer than for gas pipelines, due to the higher release inventory mass and the heavier than air density [8].
Spatial planning	This aspect was added after consultation with relevant stakeholders.
Wall thickness and corrosion allowance	The wall thickness evaluation for hoop stress considerations is based upon the methodology outlined in ISO 13623. In critical areas, a higher wall thickness is considered to give resistance to excavators and other construction equipment. The final minimum required wall thickness is determined by the addition of any required corrosion allowance, which is set in the study at 1 millimeter. Corrosions allowance is extra wall thickness that is added to compensate for a potential reduction in wall thickness by internal or external corrosion. At all places where the pipeline intersects with a high-voltage powerline, an additional assessment of corrosion potential is required [8].

4 Current Swiss technical regulatory framework for CO₂ pipelines

In this section, existing technical regulations with potential relevance for the design, construction, and operation of CO₂ pipelines in Switzerland are assessed. As no specific laws, regulations, or standards have been proposed in Switzerland for the design, construction, or operation of CO₂ pipelines to date, in a first step, existing pipeline-specific technical regulations in Switzerland are identified. Based on these, more general technical regulations which typically must be considered for the design, construction, or operation of larger infrastructure projects are added – for example, in the area of spatial design or environmental protection. The key technical aspects defined in section 3 are then assessed in the context of this extended technical regulatory framework (see section 4.1). The goal of this analysis is to provide an initial overview of existing technical regulations for pipelines and whether and to what extent they could be applied or adapted to CO₂-specific pipelines.

4.1 Extended technical regulatory framework

The gas pipeline network in Switzerland is the only large pipeline network infrastructure, with around 2,500 kilometres of high-pressure pipelines laid in Switzerland – of which about 92% are gas pipelines and 8% are oil pipelines [26]. The construction and operation of oil and gas pipelines are subject to federal supervision, with the competent supervisory body being the SFOE. The Federal Department of the Environment, Transport, Energy and Communications (DETEC) can extend this supervision to the



construction, maintenance and operation of other pipelines, provided they are owned by the Confederation or a federal body [27]. It monitors the risks associated with the construction and operation of pipelines with an operating pressure of more than 5 bar and an external diameter of more than 6 cm (high-pressure pipelines). In addition, the SFOE carries out the overall supervision of pipelines that are under the supervision of the cantons [26]. The Pipelines Act sets the basic legislative framework conditions for the construction and operation of such pipeline systems. These legal provisions are executed through the Pipelines Ordinance, which regulates the federal approval procedures, and the Pipeline Safety Ordinance, which defines the minimum safety requirements for the network and its operators [28]. The Federal Pipelines Inspectorate (FPI) is the technical supervisory authority for all pipeline systems and is responsible for the design, construction, and operation of the pipeline systems subject to the Pipelines Act. The FPI is an independent body and is not under the control of the SFOE. The basis for the execution of its role is provided by the FPI Regulations, which implement and further specify the provisions of the legislation and the ordinances [29].

The Pipelines Act refers more generally to the planning approval procedure and in particular to the Expropriation Act [30]. In addition, the Pipelines Ordinance refers to the Major Accidents Ordinance, the Environmental Protection Act, and the Spatial Planning Act [31].

Figure 2: Extended technical regulatory framework for pipelines in Switzerland.

Topic	Pipeline-specific technical regulations	General technical regulations for the design, construction, or operation of larger infrastructure projects			
	Oil and gas pipelines	Environmental impact assessment (EIA)*	Spatial planning*	Major accidents*	Expropriation
Supervision	- SFOE (overall) - FPI (technical)	- BAFU (overall) - SFOE (for oil and gas pipelines)	ARE	FOEN	Confederation
Acts	Pipelines Act	Environmental Protection Act	Spatial Planning Act	-	Expropriation Act
Ordinances	- Pipeline Ordinance - Pipeline Safety Ordinance	Environmental Protection Ordinance	-	Major Accidents Ordinance	-
Other relevant regulations	FPI Regulations	-	-	-	-

* Part of planning approval procedure

4.2 Assessment of key technical aspects

4.2.1 Planning approval procedure

Pipelines in the scope of the Pipeline Act are only allowed to be constructed with a plan approval from the SFOE. With the plan approval, all permits required under federal law are granted and no cantonal permits are required [32]. However, the respective municipalities and cantons are supposed to support the pipeline operator in the preparation of the planning approval documents. In principle, the pipeline operator is required to submit the following documents to the SFOE: a technical report, a report on the impact on the environment and on the coordination with spatial planning, and the project plans [33]. The technical report mainly includes technical information on the pipeline, corrosion protection, and the measures taken in the event of potential natural hazards to the pipeline [34]. The report on the impact on the environment and on the coordination with spatial planning mainly includes an environmental impact assessment (for details, see section 4.2.2), considerations on major accidents (for details, see section 4.2.3), and a report on the coordination with spatial planning (for details, see section 4.2.4) [31]. The project plans mainly include a general routing of the pipeline including considerations around designated areas, such as protection zones or effects on railroads and roads, safety distances (for details, see section 4.2.5) and maximum operating pressures (for details, see section 4.2.6) [35].

4.2.2 Environmental impact assessment (EIA)

EIAs are used as part of the planning approval procedure to determine whether a construction project complies with environmental law [36]. In Switzerland, there are existing EIA regulations, which are generally applied to all projects with potential impact on the environment. The main principles governing an EIA are regulated by the Environmental Protection Act and the associated Environmental Protection



Ordinance. According to the Environmental Protection Act, installations that could cause substantial pollution to environmental areas must prepare an environmental impact report before start of the construction. In principle, the report must contain all information required to assess the project's impact on the existing condition of the environment, measures for the protection of the environment, and foreseeable residual environmental impact [37]. The EIA is carried out by a competent authority that decides on the project as part of a permit, approval, or concession procedure. In general, this process is regulated on a cantonal level and carried out by cantonal authorities, unless the ordinance specifies otherwise. For oil and gas pipelines in the scope of the Pipeline Act, the EIA is part of the ordinary planning approval procedure that is regulated on a federal level by the SFOE [38, 39].

4.2.3 Major accidents

According to the Environmental Protection Act, installations which, under extraordinary circumstances, could seriously harm people or their natural environment must take the necessary measures to protect the population and the environment [37]. Further specifications regarding major accidents are set out in the Major Accidents Ordinance. The Ordinance does not specifically refer to CO₂ or CO₂ pipelines. However, pipelines in the scope of the Pipeline Act or subject to federal supervision were included in the scope of the Ordinance in 2013 [40]. Major accident risks of such pipelines are assessed in two steps: First, the pipeline operator is required to submit a short report to the SFOE, mainly including information on the planned safety measures and an evaluation of the probability of an incident causing serious damage to the population or their environment. Second, based on the short report, the SFOE either concludes the procedure or performs a more detailed risk assessment. Along this process, the FOEN (mainly for the verification of the short report and the detailed risk assessment), the FPI (mainly for the definition of the state of the art of pipelines), and the respective Cantonal Incident Office mainly (for an opinion on the short report and the detailed risk assessment) are involved. It is important to note that, for the gas pipelines, the overall assessment is solely focused on personal risks, since a natural gas leak cannot cause serious damage to the environment. Further, the assessment is not part of the planning approval procedure [41].

4.2.4 Spatial planning

Spatial planning for oil and gas pipelines is not directly regulated by the dedicated legal framework for oil and gas pipelines. The Pipelines Ordinance requires projects to be coordinated with spatial planning, in particular with the cantonal structure plans, as part of the plan approval procedure. The Spatial Planning Act, which sets the basic legislative framework conditions for the spatial development and the economical use of the land in Switzerland. The Confederation, cantons and municipalities are jointly responsible for spatial planning and the separation of construction areas from non-construction areas [42]. At the federal level, the Federal Office for Spatial Development (ARE) is responsible for spatial planning. For the planning and coordination of its tasks, the federal government prepares binding sectoral plans and concepts. On a cantonal level, the cantonal planning and building legislations and the structure plans coordinate the spatial planning in the cantons, as well as on regional and communal level [43].

4.2.5 Safety distances

For oil and gas pipelines in the scope of the Pipeline Act, the Pipeline Safety Ordinance regulates safety distances. In particular, it specifies different safety distances to other equipment, including other pipelines, buildings, roads, railways, and waterways for pipelines with an operating pressure to and from 25 bar [44]. The FPI Regulation builds on the safety distances defined in the Pipeline Safety Ordinance and further specifies and amends them for certain applications or special cases [45].

4.2.6 Maximum operating pressures

In principle, the Pipeline Act only applies to oil and gas pipelines with an operating pressure of more than 5 bar and an external diameter of more than 6 cm (high-pressure pipelines). For these pipelines, the Pipeline Safety Ordinance sets out provisions regarding maximum operating pressures. To determine the maximum operating pressure, all static and dynamic operating conditions possible in practice must be calculated, considering the special properties of the transported fluid [46]. Further, the Pipeline Safety Ordinance requires pipeline operators to establish certain safety measures that prevent the maximum permissible pressure from being exceeded as well as monitoring devices to monitor the



operating pressure [47, 48]. Typically, maximum operating pressures are already defined in the design stage of a pipeline project, since they have a direct impact on many design aspects, such as the safety distances (for details, see section 4.2.5).

4.2.7 Crossings

For oil and gas pipelines in the scope of the Pipeline Act, the Pipeline Safety Ordinance sets out provisions for crossings. In principle, no type of crossing is prohibited, but special safety distances and safeguarding measures must be adhered to. For crossings with buried conduits or other pipelines, roads, railroads, and watercourses, the Pipeline Safety Ordinance sets out specific safety distances (see also section 4.2.5) [44]. Further, the ordinance specifies safeguarding measures for crossings, such as protective plates or casing and lowering of the pipeline [47]. The FPI Regulation further specifies the provisions set out in the Pipeline Safety Ordinance and determines additional measures for certain crossings, such as increased wall thickness or the use of materials with higher requirements for fracture mechanics [49, 50].

4.2.8 Wall thickness and corrosion allowance

For oil and gas pipelines in the scope of the Pipeline Act, the Pipeline Safety Ordinance sets out provisions regarding wall thickness. Standardized pipeline steels shall be used for the manufacture of plant components. The calculation of the wall thickness of pipeline components must consider internal and external forces. For the determination of the external forces, the mechanical influences of the soil on the pipeline as well as possible temperature fluctuations shall be considered. Further, the ordinance specifies that the pipeline and its ancillary installations shall be dimensioned and calculated in agreement with the FPI [51]. The FPI Regulation further sets out calculations for wall thickness, considering, among other factors, the operating pressure and the outer diameter of the pipeline, as well as minimum standard thicknesses [52]. Further, the Pipeline Safety Ordinance sets out provisions regarding corrosion allowance. Protection against external corrosion must consist of an electrically insulating, permanently adhering pipe coating and a cathodic corrosion protection system. The materials and equipment to be used for corrosion protection as well as the respective application methods must be determined in agreement with the FPI [53]. The FPI Regulation further specifies provisions around components for corrosion protection installations, coating and isolation of the pipeline, and measures for the protection of people and against lightning strikes [54].

4.2.9 Expropriation

Expropriation is when property ownership is transferred, typically from a private owner to the government. The reason for expropriation is typically an increasing demand for building zones due to transport infrastructure projects, such as roads or railroads. In any case, expropriation must be in the interest of the public and can only be carried out with important reasons [55]. The Expropriation Act sets out the regulatory framework for expropriations, above all on the overall procedure and certain requirements that must be met. In general, the right for expropriation lies with the Confederation, but can also be delegated to other parties, such as cantons or municipalities [56]. Both the Expropriation Act and the Federal Constitution set requirements for a permissible expropriation, in particular the necessity for a legal basis for the expropriation in federal or cantonal law, an adequate public interest in the project or infrastructure causing the expropriation, and the proportionality and absolute necessity of the expropriation [57].

4.2.10 CO₂ stream composition

There are no existing or similar regulations for water content and purity of CO₂ in Switzerland. A comparison to possibly existing regulations for the composition and purity of oil or gas streams was deemed unreasonable.

4.3 Conclusion

Overall, it can be stated that the extended technical regulatory framework for oil and gas pipelines in Switzerland covers all key technical aspects that were identified to be relevant for CO₂ pipelines.



However, it remains that no specific provisions directly addressing the CO₂ case exist. Provided that an amendment to the Constitution would grant the federal government the competence to develop a (technical) regulatory framework, in principle, two options seem conceivable. CO₂-specific provisions could be included in the current technical regulations for oil and gas pipelines – in which case the SFOE could remain in its role as supervisory body and the FPI could act as an independent technical regulator. Alternatively, CO₂-specific regulations could be independently developed, following the structure of the existing technical regulations for oil and gas pipelines.

Regarding the more general technical regulations which typically must be considered for the design, construction, or operation of larger infrastructure projects, it can be concluded that these are largely independent of the respective type of infrastructure project. In this regard, this part of the technical regulatory framework could presently be applicable to CO₂ pipelines as well. Further, in the case that some of these existing general technical regulations would not meet the technical requirements of CO₂ pipelines, these aspects could be addressed separately: either in the technical regulations for CO₂ pipelines or through selective adaptation of these general regulations.

5 Assessment of international standards and national technical regulatory frameworks for CO₂ pipelines

In this section, existing technical standards and regulatory frameworks in Europe and selected countries thereof are identified. First, existing technical regulations and standards for the design, construction, and operation of CO₂ pipelines on a European level are assessed. Second, technical regulatory frameworks for CO₂ pipelines in selected European countries are identified. The aim of this comparative analysis is to identify potentially applicable options for the Swiss context from the current and potential new practices in technical regulation around Europe. Supranational issues and perspectives relevant for the connection of the Swiss CO₂ pipeline grid to a European-wide network are thus integrated into the proposed next steps for developing technical regulatory aspects (section 6).

5.1 International standards

The scope of the analysis in this section focuses on regulations and standards specific to CO₂ pipelines but does not systematically investigate more general technical regulations which typically have to be considered for the design, construction, or operation of larger infrastructure projects.

The European-wide regulatory landscape for CCS is mainly shaped by the EU and the European Commission, whereas its policies mainly focus on more overarching aspects for reaching climate neutrality rather than technical ones. The CCS Directive, on the other hand, which aims to provide a more detailed regulatory framework to be transposed into respective national laws, primarily focuses on technical aspects for storage instead of CO₂ pipelines. Accordingly, these policies and legislations are not further examined in the context of this report. At the same time, international technical standards are available for consideration and use worldwide. International standards are critical for the design and operation of Swiss CO₂ pipelines to ensure the viability of connecting them to a European-wide CO₂ pipeline network.

In general, there are many international technical standard developers around the world. For this analysis, the focus is two international standard organisations. First, standards from the International Organization for Standardization (ISO) are considered. The ISO is one of the most prominent international standards organizations worldwide, with a global network of national standard bodies, which develops and publishes international standards in technical and nontechnical fields [58]. Second, standards from Det Norske Veritas (DNV) are considered. DNV is a global expert in assurance and risk management and an international certification body, which develops and publishes standards, regulations, and recommended practices for several industries, including maritime, renewable energy, and oil and gas [59]. Both standard organisations are selected for this analysis due to the solid foundation they have historically provided for the development of national and international legislation and since many European countries directly refer to them for the development of their technical



regulations for CO₂ pipelines. In general, the use of standards is voluntary, unless they are referenced in specific EU Directives. However, countries can anchor them in their legislation, therefore making them mandatory within the respective jurisdiction [60].

5.1.1 ISO standards

As of today, the ISO's technical committee responsible for CO₂ capture, transportation, and storage published a total 13 standards, including updates, focusing on different aspects of the technology, such as capture processes, quantification and verification, or geological storage [61]. ISO 27913:2016 is the main relevant standard for considerations around technical regulatory aspects for CO₂ pipelines that are specific to the CO₂ case and not adequately covered in these standards. In general, it acknowledges the current lack of industry experience for the transport of CO₂ via pipelines and outlines a range of risks that need to be understood and effectively managed to ensure the safe transport of CO₂. Further, the standard provides a broad range of recommendations for the reliable design, construction, and operation of CO₂ pipelines. In particular, the standard focuses on aspects of CO₂ stream composition as well as safety and monitoring aspects [62]. Currently, an update of the standard is under development [63].

It is important to understand that ISO 27913:2016 builds on existing standards, mainly on ISO 13623:2017 that gives recommendations for the design, construction, and operation of on-land and offshore oil and gas pipelines. While being focused on oil and gas, it includes an important classification of CO₂ with respect to potential hazard to public safety in the most hazardous category E. For pipelines in this category, the standard sets out special requirements for public safety, particularly safety distances, in case such requirements are not defined by the country in which the pipeline is located [64].

5.1.2 DNV standards

DNV issued its first pipeline standard in 1976, and around two thirds of all new projects globally have been designed to DNV pipeline standards. DNV's pipeline standards are complemented by several recommended practices (RPs), which give more detailed guidance on how to approach specific technical aspects for different use cases [65]. The main relevant recommended practice for CO₂ pipelines is DNV-RP-F104. Overall, the objective of this RP is to provide a framework for the design, construction, and operation of CO₂ pipelines, with the goal of obtaining an adequate level of safety. In general, this RP supplements requirements in existing DNV pipeline standards. In particular, this RP focuses on composition of CO₂ streams, materials and pipeline design, construction, and operation including transport safety aspects [66].

5.2 National technical regulatory frameworks

In this sub-section, technical regulatory frameworks for CO₂ pipelines in selected European countries are identified. In the context of the novelty of CO₂ pipelines and their technical regulation in Europe, the objective is to develop an understanding of whether the investigated countries extend existing technical regulations for similar infrastructure, such as oil and gas pipelines, if new CO₂-specific technical regulations have been developed, or a mix thereof. In this sense, the scope of the analysis in this section focuses on pipeline-specific regulations and excludes an examination of broader aspects such as environmental impacts or spatial planning (which tend to be regulated broadly anyway and then applied to different infrastructure construction projects). Further, the authorities responsible for developing and overseeing technical regulations for CO₂ pipelines are aimed to be identified. Findings are restricted by the availability of documents in translatable formats and the ability to identify effective search parameters in each country's official language.

Considering that CO₂ pipeline plans in Europe are still in their early stages of development, and most infrastructure remains presently non-operational, this analysis narrows down to the most relevant European countries with the most developed plans for CO₂ pipelines. To account for this, only countries with publicly disclosed plans for onshore CO₂ pipeline networks with an announced transport capacity of at least 5 million tonnes per year are investigated [67].

5.2.1 Belgium

Belgium does not yet have a specific technical regulatory framework in place for CO₂ pipelines. However, several projects that include CO₂ pipelines are being developed, and the country has recently emerged



as the frontrunner in establishing regulation for hydrogen pipelines. Existing legal bodies, technical regulation, and permitting procedure for natural gas pipelines may be applicable to CO₂ transport, or a different regulatory framework may be developed similarly to hydrogen in the future.

The legal framework for the transmission of natural and other gases mainly consists of the 1965 Law on the transport of gaseous and other products by pipelines (“1965 Gas Act”) [68], the 19 March 2017 Royal Decree relating to safety measures for the establishment and operation of installations for transporting gaseous and other products by pipeline (“2017 Decree”) [69], and the 2021 Technical Code relating to safety measure to be taken during the design and construction of pipeline transport installations (“Technical Code”) [70]. Together, this regulatory system provides a framework for pipeline transport of gaseous and other products but does not explicitly mention CO₂ as within the scope of products.

The 2017 Decree outlines general and fundamental safety requirements for pipeline transport installations. The Technical Code specifies the detailed technical requirements for pipelines in 4 areas: design and construction, operation, risk analysis and safety management systems [71]. While the Technical Code does not recognize or address CO₂ as a potential fluid for pipeline transport, the technical regulations it outlines for natural gas pipeline construction, design, installation, and testing may be applicable to these projects. Additional standards that are applicable by category of fluid (D for natural gas, subcategories according to design pressure) may also apply [70]. The most recent Technical Code was proposed by the non-profit organization FETRAPI, the Federation of Pipeline Transporters, composed of representatives from several authorized transmissions system operators (TSOs) [72]. Similarly, it is possible that industry experts will be responsible for the development of technical standards for CO₂ pipelines, which are then integrated into the legal framework.

Currently, the installation and operation for transporting gaseous and other products via pipeline is subject to federal authorization by the Ministry of Energy, as well as regional land use planning and environmental authorizations [73]. Authorization approvals are advised by the Commission for Electricity and Gas Regulation (CREG). [74, 75]. Similarly, amendments to the Technical Code for gas pipelines are approved by the Ministry of Energy but advised upon by the Quality and Security, and Energy Administrations of the Federal Public Service [70]. Requirements specific to authorizing CO₂ transport-specific infrastructure are not yet developed.

In the absence of CO₂-specific technical regulations, it is unclear how in-progress projects involving CO₂ transport are determining what standards to comply with, and how future developments of a regulatory framework will interact with existing infrastructure. For example, the existing natural gas transmission network is managed by Fluxys Belgium SA, a CREG-certified TSO headquartered in Belgium [76]. Fluxys is currently adapting existing infrastructure to transport CO₂ and hydrogen in efforts to position Belgium as a key export and transit country in Europe with the capacity required to transport 30 million tons of CO₂ by 2030 [77-79]. As Fluxys representatives make up nearly half of FETRAPI members [70], it is possible that Fluxys’ choice of technical standards will retroactively inform proposals for a CO₂-specific Technical Code in the future.

However, the Belgian Hydrogen Act adopted on 25 July 2023 provides a case study for an alternative path of development for a CO₂-specific regulatory framework [80-82]. The legislation establishes procedures and conditions for the designation of a single regulated operator of the hydrogen transport network (HSO) within Belgium [83]. The HSO will be responsible for developing and implementing a hydrogen network development plan that complies with unbundling (open and non-discriminatory access) conditions. The Act notably excludes the applicability of the Belgian Gas Act – except where an explicit reference is made – and outlined the duties and powers of CREG as the independent regulator for the transport of hydrogen [81]. If a similar regulatory framework is developed by Parliament for CO₂ transport, characteristics could include a fully integrated CO₂ transport network, operated by a legal monopoly, following an unbundling regime.

5.2.2 Denmark

Carbon capture and storage play a key role in Denmark’s net-zero targets, and the government has recently further accelerated their plans to scale-up Danish CCS by 2030 to 2029 [84]. Denmark has an estimated potential to store 13 million tons of CO₂ annually underground by 2030 and expects their first CO₂ capture facilities to be ready by the end of 2025. However, technical regulations specifically for CO₂-transport pipelines are yet to be developed. The current regulatory framework focuses largely on capture and storage infrastructure, not transport by pipeline. Past and ongoing CO₂ pipeline projects



have thus sought out third-party technical verifications and are investigating the potential to reuse existing offshore pipelines.

The authority responsible for the environmental and safety aspects of CCS, the Danish Energy Agency, has compiled a list of political agreements and legislation relevant to the CCS area [85]. The only directly applicable regulatory measure for CO₂ transport by pipeline is the 27 October 2021 Promulgation of the Act on Environmental Assessment of Plans and Program and of Specific Projects (EIA). The Act mandates that proposed CO₂ pipelines for geological storage must conduct environmental impact assessments and obtain written approval by the Minister for Climate, Energy, and Supply [86]. Notably, none of the listed regulatory instruments specify technical standards for CO₂ or other pipeline construction. The Use of the Danish Subsoil Act does contain special provisions regarding the geological storage and piped transport of CO₂. The relevant section of the Act mainly addresses procedures for licensing CO₂ transport networks and does not discuss technical requirements for pipelines [87].

The availability of existing offshore pipelines and shipping as CO₂ transport methods for pilot projects may contribute to the lack of development in regulation for constructing and designing new pipelines specifically for CO₂ streams. Project Bifrost, a research and demonstration project to evaluate the potential for CO₂ transport and storage in the Danish North Sea, assessed the potential conversion of existing offshore gas pipelines for CO₂ transportation and found reuse to be feasible. The study's findings did not specify what, if any, technical standards for pipelines were referenced [88, 89]. Denmark's TSO Energinet was also responsible for constructing 105 km of a new offshore gas pipeline connecting Norway, Denmark, and Poland. While the pipeline will be used to transport natural gas and not CO₂, the Danish TSO chose to enlist technical verification from the third-party risk management expert DNV [90]. Pipeline approval criteria were comprised of the Danish Continental Shelf Law, DNV standards for submarine pipeline systems and the underlying DNV certification regime [91, 92]. Past projects involving Danish offshore natural gas pipeline construction, including the Nord Stream 2, also followed DNV technical codes and standards [93]. While both pipeline projects transport natural gas and CO₂, the use of DNV technical standards may be applicable to CO₂ pipeline projects. Notably, DNV has developed and continues to improve technical standard DNV-RP-F104 for the design, construction, and operation of carbon dioxide pipelines which could inform future regulatory developments [94, 95].

5.2.3 France

France is in the early stages of developing CCTS activities and does not yet have a technical regulatory framework for the transport of CO₂. The Prime Minister recently presented a draft CCUS strategy on June 23, 2023 that affirmed the need to develop pipeline logistics, which will ultimately constitute the backbone of regional CCUS networks and export hubs [96]. This Strategy notable entrusts the Energy Regulatory Commission (*Commission de Régulation de l'Energie*) with the responsibility of supervising and proposing an adapted regulatory framework for CO₂-transport infrastructure [97]. Under the French Energy Code, the Energy Regulatory Commission is also mandated with regulating the French electricity and gas markets, including natural gas [98]. While current natural gas pipeline standards do not refer to CO₂, and CO₂-transport regulations are yet to be developed, the Energy Regulatory Commission may propose adapting CO₂ pipeline requirements from the existing French Energy and Environment Codes.

As outlined in the French Environmental Code, the construction and operation of oil and gas pipelines must be authorized by the Ministry of Energy, the ministry in charge of pipeline transportation safety, or a prefectural order, depending on the substance being transported. The Environmental Code also sets the procedure for receiving the governmental authorisation required to construct and operate natural gas transportation pipelines, as well as application file requirements. [98]. Notably, technical standards include conducting a hazard study and risk analysis which evaluates the probability of occurrence, the kinetics and the severity of potential accidents according to a standardized or explicit methodology. A risk analysis and public enquiry must also be conducted and the pipeline must comply with minimum distance and other safety requirements [99].

Technical standards for natural gas pipelines are contained in the relevant *Normes Françaises et Européennes* (NF EN) which are not publicly available [100]. The standards referenced by the French TSO GRTgaz, for example, specify technical requirements for pipeline design, construction operation and aspects relating to safety, environment, and public health for pipelines operating pressure over 16



bar, and separately for 16 bar or less [101]. Technical standards are developed by the French Standardization Association (AFNOR), which represents France to the ISO and the European Committee for Standardization [102]. Similarly, AFNOR standards, drawing from the ISO, may be involved in the development of a regulatory framework for CO₂ pipelines.

As part of France's CCUS Strategy, the GOCO₂ decarbonization project is developing the transport of CO₂ by pipeline for industrial sites in the Greater West region of France [103]. The project aims to transport and export up to 4 million tons of CO₂ per year in 2050. The technical standards that will be used in the pipelines' development are not publicly available.

5.2.4 Germany

The German Energy Industry Act (*Energiewirtschaftsgesetz – EnWG*) refers to the German association for gas and water (*Deutscher Verein des Gas- und Wasserfaches – DVGW*) as the recognized standardization body for technical regulations for pipelines [104, 105]. In general, DVGW standards form the basis for all activities in the German gas and water industry and typically comprise of technical standards and DIN standards. The DVGW is organized along expert panels and technical committees and, since recently, has a technical committee whose scope of work includes the topics of properties and infrastructures for the transport of CO₂ [106]. Further, the DVGW has several standards that are relevant for the design, construction, and operation of CO₂ pipelines, with the ones possibly relevant for CO₂ pipelines briefly described in the following:

- **G 463 standard:** This standard establishes design and construction rules for gas pipelines for a design pressure of more than 16 bar. It is mainly based on general principles for the design, construction, operation, and maintenance of high-pressure gas pipelines as outlined by the German national organization for standardization (*Deutsches Institut für Normung – DIN*). These general principles represent minimum requirements, which are built upon in the DVGW standard on the basis of the proven safety concept of the German gas industry. The standard does not specify rules for CO₂ pipelines [107].
- **G 466-1 standard:** In line with the G 463 standard, this standard establishes operation and maintenance rules for gas pipelines for a design pressure of more than 16 bar. Again, the standard does not specify rules for CO₂ pipelines, but the scope of application is not limited in terms of the maximum permissible operating pressure [108].
- **C 260 standard:** In 2022, the DVGW published a standard that describes the characteristics and requirements for the properties of a CO₂ stream for transport in steel pipes and also contains recommendations and notes regarding the effects of CO₂ streams on the design and operation of pipelines. The code explicitly focuses on CO₂ streams that originate from capture processes and are transported for the purpose of durable storage. The standard differentiates CO₂ stream compositions depending on the source, for example biomass power plants, cement production, or certain chemical processes, and their influence on the design and operation of CO₂ pipelines [109].
- **C 463 standard:** Together with the C 260 standard, the DVGW published this standard that sets out requirements for the design and construction of CO₂ pipelines, such as maximum operating pressures or wall thickness. For more pipeline-general provisions, it explicitly refers to the G 463 standard [110].
- **C 491 standard:** In 2023, the DVGW published a draft of the C 491 standard on installations in CO₂ transport systems. C 491 directly builds on the two CO₂-specific standards that were published in 2022 by supplementing safety requirements for the design, construction, and operation of installations that regulate, control, measure, compress, pump, mix, separate, shut off, or depressurize CO₂ streams in gaseous, liquid, or dense phase [111].

Open Grid Europe (OGE), the developer of the planned German CO₂ pipeline network, on its website refers to both the C 260 standard and the C 463 standard [112]. As for the composition of the CO₂ stream, OGE refers to their own current proposal for the composition of CO₂ to be transported with their pipeline, while stating that they are open exchange with potential customers and partners in order to further develop and optimize requirements [113]. The planned grid will have the capacity to transport 18 million tons of CO₂ a year [114].

5.2.5 Netherlands



Even though several CO₂ pipeline projects are being developed in the Netherlands, so far, no specific technical regulatory framework for CO₂ pipelines has been established. Furthermore, existing pipeline regulations do not specifically include CO₂ within their scope. So far, the regulatory framework for mining have typically been used as a starting point for considerations around technical regulations for CO₂ pipelines [115]. The Dutch Mining Decree (*Mijnbouwbesluit*) defines rather general safety requirements, such as protection against corrosion or prevention of damage of the environment. For more specific requirements around design, construction, and operation of pipelines the Decree refers to the Mining Regulation (*Mijnbouwregeling*) [116]. The Mining Regulation, in turn, does not establish any technical provisions for pipelines itself, but refers to several national and international standards [117]. The international standard referenced is the API Specification 17J. The national standards referenced were all developed by the national standard institute (*Nederlandse Norm – NEN*), with the ones possibly relevant for CO₂ pipelines briefly described in the following (not publicly available) [118]:

- **NEN-3650-1:** sets out general rules for the design, construction, and operation of pipelines regarding safety aspects for people, the environment and property.
- **NEN 3650-2:** sets out additional specifications for steel pipelines
- **NEN 3651:** sets out additional requirements for pipelines in or nearby important public works
- **NEN 3655:** sets out functional requirements for a safety management system for pipelines for the transport of hazardous substances

Furthermore, the Netherlands provide an example of how CCTS projects can set out technical regulations for their pipeline. The CO₂ hub project Porthos made publicly available their guideline on CO₂ transport and storage conditions, in which they partly focus on technical aspects for their CO₂ pipeline. The rules set out in the guideline itself are mainly focused on the operation of the pipeline, and include maximum operating pressures and temperatures, CO₂ stream composition requirements, a safeguarding system, and more general operating principles. Usually, the standard refers also refers to applicable national and/or European legal, technical, safety and environmental provisions as well as international standards, that either complement the rules set out in the guideline or even fully regulate certain aspects. As for maximum operating pressures, for example, the guidelines refers to one national standard as described before (NEN-3650-1) as well as to a European standard on gas infrastructure (DIN EN 12186). Overall, the Porthos guideline acknowledges that, in many cases, standards regarding natural gas must be applied due to a current lack of comparable CO₂-specific standards [119]. The project aims to transport and store around 37 million tons of CO₂ over 15 years [120].

5.2.6 Norway

Norway is the most CCTS-experienced country in Europe, as the Sleipner and Snøhvit projects have been in operation since 1996 and 2008, respectively. Together, the two projects have geologically stored over 25 million tons of CO₂. While the Sleipner project sources the CO₂ from natural gas production on site, the Snøhvit project captures CO₂ onshore, with transportation by a 150 kilometre CO₂ pipeline to the offshore storage site [121]. Furthermore, several commercial projects are planned to become operational within the next few years, such as Norcem Brevik, Northern Lights, or Høvsfjord Oslo Celsio [122]. Regarding CO₂ pipeline transport, the Norwegian state-owned multinational energy company Equinor recently announced two large-scale projects: a 1,000 km pipeline to transport CO₂ from Belgium to the Norwegian continental shelf with a transport capacity of 20 to 40 million tonnes of CO₂ per year as well as a 900 km pipeline from Germany to storage sites in Norway with a transport capacity of 20 to 40 million tonnes of CO₂ per year [123, 124].

The technical regulatory framework for CO₂ pipelines in Norway is shaped by two government agencies that are mainly responsible for regulating the oil and gas industry. First, the Norwegian Petroleum Directorate (NPD) acts as a government agency that is mainly responsible for the regulation of the national oil and gas resources. Second, the Petroleum Safety Authority (PSA) acts as a supervisory agency that is mainly responsible for regulations around safety, emergency preparedness and the working environment in the oil and gas industry. Both agencies report to the Ministry of Petroleum and Energy [125, 126]. In recognition of the additional responsibilities and work of the two agencies beyond the oil and gas industry, namely in the area of CCTS, the two agencies will change their names as of beginning of 2024. The NPD will be referred to as the Norwegian Offshore Directorate, while the PSA will be called the Norwegian Ocean Industry Authority [127]. Both agencies have developed and published regulations including technical aspects to consider for CO₂ pipelines:



- **Regulations relating to exploitation of subsea reservoirs on the continental shelf for storage of CO₂ and relating to transportation of CO₂ on the continental shelf** (developed by NPD): It provides a rather general overview of aspects that need to be considered when designing a CO₂ pipeline, however, without actually specifying them.
- **Framework regulations** (developed by PSA): In principle, the regulation provides more general rules related to health, safety, and the environment for oil, gas and similar activities. For CO₂ pipelines specifically, it addresses more general safety requirements but does not provide any specific rules nor includes the design or construction of CO₂ pipelines [128].
- **CO₂ safety regulations** (developed by PSA): In principle, the regulation is based on the Framework regulations and other regulations regarding the health, safety, and the environment for oil and gas. It is then adapted to the risk conditions for CO₂ pipeline transport and CO₂ storage. For CO₂ pipelines specifically, the regulation provides more general rules for the design, construction, and operation of CO₂ pipelines, but typically refers to existing regulations focused on oil and gas activities [129].

5.2.7 United Kingdom (UK)

As of September 2023, the experience for the design and operation of CO₂ pipelines in the UK is rather limited [130]. At the same time, the government expects large shares of captured CO₂ to be transported by pipelines in the longer term [131]. The UK has seen a steady rise in proposed CCTS projects, with the first smaller projects expected to become operational as of 2024 [67], indicating the need for CO₂ pipeline networks to service industrial hubs such as the Humber industrial cluster, including the Drax bioenergy with carbon capture and storage (BECCS) facility, which would transport captured CO₂ via pipeline to storage locations in the North Sea [132, 133].

In the UK, the Health and Safety Executive (HSE), responsible for regulating health, safety and integrity aspects for natural gas and other applicable pipelines, has emerged as the national body for determining the technical regulatory framework for CO₂ pipeline networks, in particular safety aspects [131]. As of September 2023, no specific regulatory framework for CO₂ pipeline transport has been established. However, the HSE provides guidance on CO₂ pipeline transport and specifically refers to existing legislation that can be used to effectively regulate the safety of CO₂ pipelines [130, 134]. As for existing legislation, the HSE mainly refers to the Pipelines Safety Regulations 1996 (PSR) which defines rather broad requirements for the safe design and operation of pipelines [135, 136]. HSE guidance builds on these broad requirements and defines a set of more CO₂-specific aspects that need to be carefully considered by designers and operators of CO₂ pipelines, such as corrosion, operating pressure, or stream composition. However, the HSE primarily only describes which sub-aspects require special attention but refrains from defining actual technical specifications. For these, the HSE ultimately refers to European standards and other codes of practice that are likely to be accepted in the UK if the respective provisions provide for equivalent levels of safety. In particular, it refers to DNV's recommended practice (DNV-RP-F104; see section 5.1.2) [136].

Furthermore, the PSR also identifies additional requirements for major accident hazard pipelines which transport dangerous fluids, such as further compliance with laws under land use planning. Although CO₂ has not been defined as a dangerous fluid and is therefore not subject to any extraordinary regulatory compliance yet, it may be assumed that CO₂ pipelines would be considered major accident hazard pipelines due to the potential containment of toxic components in the CO₂ stream as well as the operating pressure in dense phase transport modes. The PSR and PSSR are complemented by relevant industry standards. For hazardous pipelines including such for transport of CO₂, requirements are specified in the "Code of Practice for Pipelines – Steel Pipelines on Land" [115, 137, 138].

5.3 Conclusion

Amongst the analyzed countries, the status of technical regulation for CO₂ pipelines varies widely. However, no single country has fully developed a comprehensive technical standard to regulate CO₂ pipelines. Thus far, only Germany and Norway have published specific regulations pertaining to CO₂ pipelines, but the technical aspects for both remain broad and focus largely on safety considerations.

In determining who is responsible for developing a regulatory framework for CO₂ pipelines, some countries have explicitly designated the responsibility to existing national regulatory bodies as an



extension of their mandate: for example, Germany's DGWV, France's Energy Regulatory Commission, or the UK's HSE. Most of these bodies are the existing authority for regulating natural gas and oil pipelines. For other countries, the relevant authority for issuing CO₂ pipeline licenses and permits has been identified, but not yet the authority for developing technical standards. Interestingly, it is also possible that a legal instrument such as the Dutch Mining Code can be the authority in identifying and specifying which technical standards must be used in pipeline construction and operation. Notably, Norway is changing the names of two governmental agencies to reflect the transition of their authority to include CCTS regulations and the development of technical standards for CO₂ pipelines. Similarly, Germany's DGWV has formed a Technical Committee specifically responsible for the technical aspects of CO₂ transport infrastructure. It is possible that the delegation of this role to more specified authorities, rather than adding to the responsibilities of large existing regulatory bodies, is conducive to accelerating the development of technical regulations.

Due to the lack of information and regulations available on a national level, ongoing or past gas and CO₂ pipeline projects were investigated to understand potential sources or references for future technical regulation. The technical standards themselves were derived from a variety of sources, and sometimes combined due to their often-specific scope to establish a comprehensive framework. The Netherlands and France currently implement technical standards for natural gas pipelines that are developed by their respective national standardization bodies. In other cases, the same national regulatory bodies identified above also developed the technical standards that currently apply to gas pipeline more generally and could be extended to the transport of CO₂. In the case of Belgium, technical standards are proposed to the appropriate regulatory authority by industry professionals and TSOs. In previous projects, Denmark has foregone attempting to extend existing national technical regulations in favor of applying third-party (DNV) technical standards for their offshore pipelines.

In the absence of comprehensive technical regulations for CO₂ pipelines, countries have compiled best industry practices, natural gas precedents in national law, regional (EU) standards, and international standards in a variety of formulations for application to projects. This patchwork approach may continue as CO₂ infrastructure projects proceed at a faster rate than the development of technical regulations for these pipelines. Alternatively, the case of Belgium's Hydrogen Act highlights the possibility of a single federally designated system operator and regulator for the entirety of national CO₂-transport grids, as Belgium has established for its hydrogen infrastructure.

6 Conclusions and possible next steps

The analysis has shown that the development of legislation and technical regulations for CO₂ pipelines need to be tackled with a phased approach due to a number of gaps in the existing regulatory framework. First, the general competences and authority for the development of legislation and technical regulations for CO₂ pipelines need to be defined. Currently, the Constitution only provides the federal government with the basis for the development of legislation on energy technologies, including regulations on oil and gas pipelines. However, there is no constitutional basis for comprehensive technical regulation of CO₂ pipelines at the federal level. This leaves the government with three different options on how to approach the development of legislation and technical regulations for CO₂ pipelines:

- Option 1: Based on the currently applicable constitutional basis, the competence for the development of legislation and technical regulations for CO₂ pipelines remains with the cantons, i.e., no federal competence.
- Option 2: Amendment of the currently applicable constitutional basis, giving the competence for the development of legislation and technical regulations for CO₂ pipelines to a (new) federal authority.
- Option 3: Application of Article 81 of the Federal Constitution, which states that "the Confederation may in the interests of the country as a whole or a large part of it carry out and operate public construction works or provide support for such construction works".

Second, no extensive technical regulations or standards focusing on the transport of CO₂ through pipelines have been implemented in Switzerland so far. Therefore, independent of the overarching regulatory regime that is opted for above, at some point, technical regulations specific to CO₂ pipelines



will need to be developed – either on cantonal level or federal level. There are several relevant sources from which the technical standards and regulations could be developed by the designated authority.

In Switzerland, the only reference point for technical pipeline-specific regulations are the currently existing regulations on oil and gas pipelines. In principle, these could either be supplemented by CO₂-specific aspects or used as a starting point for the creation of an independent technical regulatory framework for CO₂ pipelines. More general technical regulations which typically must be considered for the design, construction, or operation of larger infrastructure projects – for example, spatial design or environmental protection – are largely regulated independent of the application case and could also be applied to CO₂ pipelines. Taking the existing oil and gas regulations as well as the more general technical regulations together, it can be concluded that there is an existing basis and structure for how a technical regulatory framework for CO₂ pipelines could be developed. For the aspects specific to CO₂ pipelines, existing regulations from other countries as well as international standards could be consulted. An assessment of selected countries in Europe shows that most of them have or have had a similar starting position as Switzerland: there are no comprehensive technical regulations for CO₂ pipelines, which is why precedents from the oil and gas sector in national law, regional norms and international standards are compiled in a variety of formulations to develop a technical regulatory framework for their respective CO₂ pipelines.

Overall, the tools to develop technical regulations for CO₂ pipelines in Switzerland are in place. The critical questions that need to be addressed in the next steps are the following:

- Is the basis for the development of legislation for CO₂ pipelines left on cantonal level or established on a federal level?
- Are technical regulations for CO₂ pipelines included in existing regulations (for example oil and gas pipelines) or newly developed in an individual and independent technical regulatory framework?



Abbreviations

AFNOR:	French Standardization Association
ARE:	Federal Office for Spatial Development
BECCS:	Bioenergy with Carbon Capture and Storage
CCS:	Carbon Capture and Storage
CREG:	Commission for Electricity and Gas Regulation
CST:	Cargo Sous Terrain
DETEC:	Department of the Environment, Transport, Energy and Communications
DNV:	Det Norske Veritas
EIA:	Environmental impact assessment
EOR:	Enhanced oil recovery
FOEN:	Federal Office for the environment
FOJ:	Federal Office of Justice
FOT:	Federal Office of Transport
FPI:	Federal Pipelines Inspectorate
HSE:	Health and Safety Executive
ISO:	International Organization for Standardization
NPD:	Norwegian Petroleum Directorate
OGE:	Open Grid Europe
PSA:	Petroleum Safety Authority
PSR:	Pipeline Safety Regulation
RP:	Recommended Practice
SFOE:	Swiss Federal Office of Energy
UK:	United Kingdom
VBSA:	Swiss Association of Waste Treatment Plant Operators



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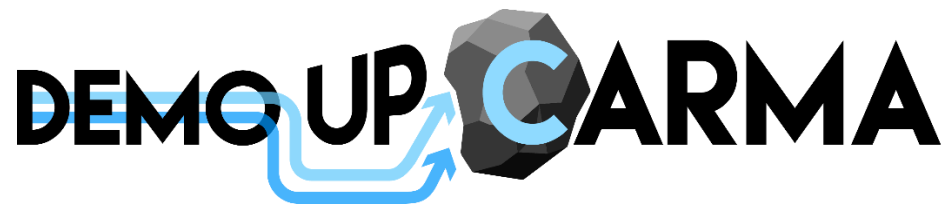
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Deliverable 5.9: Organizational and financial models for future CO₂ infrastructure

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1 Introduction

1.1 Background and objectives

Overall, the topic of organizational and financial models for future CO₂ pipeline infrastructure in Switzerland is very new and unexplored in both academia and practice. The envisioned CO₂ pipeline network will be a new national and transnational infrastructure, and so far, no organizational and financial models have been proposed in Switzerland. Similar cases of network infrastructures exist, such as, for example, gas pipelines, electricity transmission grids, water supply and a highway network. However, all these infrastructures have grown over a very long-time horizon, and it is currently unclear if their organizational and financial models are suited for the development of a CO₂ pipeline network at a relatively fast pace. In addition, several countries, with the UK being the most advanced, have already started to outline plans for financing a national CO₂ pipeline infrastructure and offer useful examples to build on.

The main objective of this subtask is, therefore, to outline and analyse organizational and financial models that could be considered for a CO₂ network infrastructure for transport by pipelines in Switzerland in a way (i) that provides a comprehensive starting point for discussions among practitioners, policy makers and academia on how to approach the establishment of organizational and financial models for a CO₂ pipeline network in Switzerland, and (ii) that serves as a basis for the detailed academic research in “*Subtask 2.1 - Investment and financing needs along the supply chain of CCS and CCU*” and “*Subtask 2.2 - Effective support policy designs for mobilization of CCS and CCU finance*”. Furthermore, this analysis exploits synergies with and inputs from the H2020 EU Project “ACCSESS” (in which ETH is a founding partner), where organizational and financial models for a CO₂ network infrastructure in the broader European context are being investigated.

1.2 Procedures and methodology

The feasibility, as well as the costs of such a CO₂ pipeline network in Switzerland, have been analysed in a study conducted by Saipem and led by the Swiss Association of Waste Treatment Plant Operators (“VBSA”). A possible network connecting 32 emitters and two collection sites (Basel and Collombey) via two main trunklines (east and west) would require capital expenses (“CAPEX”) between EUR 2.7 and 3.1 billion **Error! Reference source not found.** Building on these findings, the investment in a Swiss CO₂ pipeline network is characterised and defined in terms of (i) investment needs, (ii) potential funders and ownership, (iii) coordination and regulation requirements, (iv) revenue model, (v) risk management, and (vi) cost of capital. Each of these elements is described in the specific considerations made for investments in a Swiss CO₂ transport network.

As the next step, models of how such an investment could be organised and financed are examined in three different sets of comparable precedent cases:

- (i) At first, the organizational and financial models that are used or proposed for CO₂ pipelines in Europe are analysed. The history of funding CO₂ pipelines in Europe is briefly described and current plans for large-scale CO₂ pipeline funding in three selected European countries, namely Germany, the Netherlands, and the UK are investigated. These countries have been identified as the most relevant cases for consideration due to their state of progress and the availability of accessible information at the time of conducting this research.
- (ii) Secondly, given the very limited amount of practical experience found in funding CO₂ pipeline infrastructure in Europe, a broader view is taken on the case and search for organizational and financial models that have been used in Europe for other similar infrastructure assets, which could potentially be considered as organizational and financial models for the Swiss CO₂ pipeline network. Regulatory business models are identified as the most interesting funding and governance mechanism based on the characteristics defined previously and take a deeper look at this model.
- (iii) Thirdly, the organizational and financial models used for gas pipelines, electricity grid, water transmission networks and highways in Switzerland are analysed.



Lastly, the findings and the key open issues that require future research are summarized. Due to the novelty of this topic and the scarcity of similar models in academia, the work and outcome of this subtask are mainly based on practitioner literature and guidance. Findings of this research as well as the assessment for the Swiss context have been discussed with finance practitioners during the work.

Consequently, this report provides an extensive overview of potential organizational and financial models for CO₂ pipeline networks in Switzerland and serves as a starting point for further in-depth analysis to provide conclusive recommendations.

2 Characterising the Swiss CO₂ pipeline network

In this section, the investment decision in a Swiss CO₂ pipeline network is characterised in terms of (i) investment needs, (ii) potential funders and ownership, (iii) coordination and regulatory requirements, (iv) revenue model, (v) risk management, and (vi) cost of capital. Each of these elements is described in the specific considerations developed about investing in a Swiss CO₂ transport network. While they represent the most important aspects identified in the analysis, these considerations are only the first attempt to characterise investments in such networks in Switzerland. Additional research, including in-depth interviews with all relevant stakeholders, will be necessary for the future to complete the current understanding of all the elements that need to be considered prior to designing the funding and governance mechanism for a Swiss CO₂ transport network.

2.1 Investment needs in Switzerland

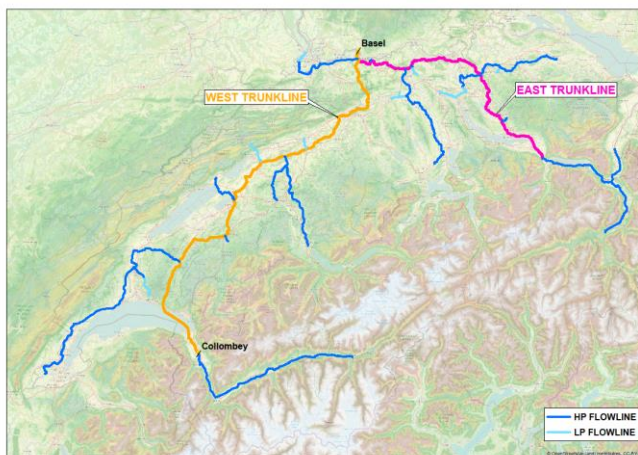


Figure 1: CO₂ pipeline network infrastructure in Switzerland **Error!**

According to a study conducted by Saipem and led by the VBSA **Error! Reference source not found.**, in Switzerland, CAPEX between EUR 2.7 and 3.1 billion would be required for a scaled-up CO₂ network including pipelines, compression stations at the emitters, and compression stations for the export pipeline, with operating costs of around EUR 200 million per year. This estimate assumes that Swiss emitters with flowrates higher than 100,000 tons of CO₂ per year (Saipem considered 32 emitters in total) would be connected to the CO₂ transportation network. The envisioned network would have an overall transport capacity of around 7.5 million tons of CO₂ per year which includes a planned flowrate

overdesign capacity of 130%. The total length of the planned routes would amount to around 1,000 kilometres, consisting of two main trunklines (east and west) to connect the largest emitters and dedicated flowlines reaching the emitters further away (see Figure 1).

In terms of investment size, such investments are not unprecedented in Switzerland. For example,

- (i) the FABI expansion program for the train network in Switzerland will cost CHF 6.4 billion for the first expansion in 2025 and CHF 12.89 billion for the second expansion until 2035 [1],
- (ii) the NEAT Gotthard-Basistunnel had a construction period of 17 years with total costs of CHF 23 billion [4],
- (iii) the Swiss military is planning to purchase 36 F-35 jets, which will cost CHF 6 billion [5].



2.2 Potential funders and ownership

2.2.1 Public funding and ownership

Given the strong credit position of Switzerland, from a purely financial point of view, public funding at the federal government level would be the most cost-efficient way to finance a CO₂ network infrastructure for transport by pipeline. However, the Federal Constitution of the Swiss Confederation currently only provides the basis for the development of energy technologies at the federal government level **Error! Reference source not found.** While CO₂ emissions are related to energy production, it is unclear whether a CO₂ transport network could fall into this definition and be funded at the federal government level. For the purposes of this report, a conservative approach is taken, and it is assumed that, if funded publicly, a CO₂ transport network would need to be funded and regulated at the level of cantons. In the future, a dedicated legal analysis will be necessary to clarify this point **Error! Reference source not found.**

Swiss cantons have historically had a slightly higher cost of funding compared to the Swiss Confederation [7] due to various factors, such as lower liquidity of their bond issuances, but overall, the cost of funding would remain very low. In case the cantons decide to fully fund the infrastructure on their own, they would most likely issue additional bonds to various financial investors to supply the required liquidity. Project-linked bonds could be considered in such an instance but would probably only be fundable if all or at least the hard-to-mitigate risks of the project (see Section 2.5) remain with the canton.

In case the CO₂ pipeline network is funded by the cantons, the key challenge becomes the coordination among them. Given the number of investment decisions that need to be taken and various interdependencies, the set-up of a centralized funding and ownership entity will probably be necessary to optimize the process and, hence, reduce the overall costs. Indeed, it has been found in one study (i) that an integrated approach to CO₂ pipeline infrastructure offers the lowest average cost on a per ton basis for operators over the life of the project if sufficient capacity utilization is achieved relatively early in the life of the pipeline, and (ii) that without incentives to encourage the development of optimized networks, individual project developers are likely to build point-to-point pipelines that are sub-optimal from a system perspective [7].

Setting up a centralized funding and ownership entity among cantons is likely to be quite challenging and would take a significant amount of time and negotiations. For example, the number of pipelines to be laid within the area of the canton is most likely not proportionate to the amount of CO₂ emissions to be captured and transported in the canton but rather depends on the position of the canton in the whole pipeline cluster and the size of the canton, amongst other things. Complex decisions will need to be made on how to split the costs of funding and decision-making power among cantons. The organizational and financial models for the Swiss electricity grid and the operational setup of the Swiss Federal Roads Office ("ASTRA") could potentially serve as reference points, as analysed later in the report (see Section 5).

Recently, there has also been a parliamentary proposal to the Swiss Confederation to establish its own investment bank – the Swiss Green Investment Bank – intended to focus primarily on high-risk green investments, in which private investors are reluctant to invest. The goal is to reach an investment volume of CHF 10 billion in ten years, mainly through payments from the federal government, but also from smaller cantonal banks or investment foundations [9]. Provided that a CO₂ pipeline network meets the intended investment criteria of the Swiss Green Investment Bank, it could be used as a funding mechanism. However, to coordinate the complex development of a CO₂ pipeline network in Switzerland, an additional organizational setup would likely be necessary.

2.2.2 Private funding and ownership

It may also be decided that attracting direct private capital is desirable for the project to increase the amount of available funding, share some or all the risks with the private sector, or enhance operational and managerial skills available in the funders group. Both strategic and financial investors could be considered for the project:

- (i) **Strategic investors** would not only participate in the project for financial reasons, but they would also bring their strategic point of view on investing. They are especially valuable if they



know the infrastructure asset and are familiar with its operations. Potential strategic investors that could be considered for a CO₂ transport network include:

- a. **A mandated pipeline construction company** (e.g., Saipem) would be of particular value in the group of funders as the construction company would then have “*skin in the game*”. In addition, potential operators of the German portion of the pipelines (e.g., OGE or others, depending on future developments) could take a small stake to ensure alignment of interests across the border and provide additional operational expertise. However, this is only meaningful if the pipeline construction company has sufficient funds for the required investment and a relatively secure credit situation.
 - b. **Swiss gas transmission industry players**, who may bring general expertise in operating pipelines.
 - c. **Emitters**, who could consider joining for, as an example, privileged rights for CO₂ transport in the future in exchange for a commitment on volumes to be transported.
- (ii) **Financial investors** would participate in the funding of a CO₂ pipeline network primarily for the financial return. In general, typical institutional funds and large infrastructure funds are likely to be interested in such a project, provided it is well structured to generate long-term income streams with a government-like risk profile that could be understood and assessed. In this case, sufficient investor appetite could be expected given the current investment climate, under the assumption that:
- a. Long-term fixed-income backed by secure public entities is attractive to investors;
 - b. Most large infrastructure funds are currently cash-rich;
 - c. Many institutional lenders are looking for “green” investment opportunities.

In Europe, non-CO₂ pipelines are currently mostly financed by financial investors as there is enough operational expertise among financial investors. At the same time, given the novelty of a CO₂ transport network, a strategic investor could bring significant value to the project and may be necessary.

2.3 Coordination and regulatory requirements

The build-up of a CO₂ transport network can be characterized as a project of high novelty, high complexity, with long lead times, multiple interdependencies, strong link to and dependence on climate policy (in Switzerland and in Europe), and potentially many unknown events in the course of a lifetime for pipelines, i.e., of 50 to 100 years. In this context, it is important that the selected organizational and financial model:

- (i) allows for relatively high flexibility and adaptability, at least in the first years of operation;
- (ii) is linked to climate and other relevant policies of the federal and cantonal administrations;
- (iii) consists of very few entities or has at least a way to centralize actions in order to:
 - a. take strategic decisions – e.g., on the need of oversizing the pipelines at the beginning to accommodate higher volumes in the future;
 - b. coordinate interdependencies between the many stakeholders of the project as well as internationally;
 - c. provide detailed technical and operating guidelines (especially, given the conservative assumption that the Federal Constitution of the Swiss Confederation does not provide for the possibility of detailed regulations of the CO₂ transport network at the federal level);
 - d. manage the timelines – e.g., lenders to any part of the chain of connected projects have to ensure that all the elements will be developed on time to ensure timely debt repayment;
 - e. minimize difficulties in the allocation of responsibility;



- f. ensure that different modes of CO₂ transport (pipelines, ships, barges, trains, trucks) are planned according to their specific merits and that infrastructure is developed to serve different purposes over time.

As already briefly discussed in Section 2.2, a set-up of a centralized entity or entities to accelerate and supervise the development of a CO₂ transport network in Switzerland may be desirable to address all these aspects. In addition, the CO₂ pipeline network is likely to become a natural monopoly. Considering this, an organizational setup with a regulatory oversight might be desirable to ensure fair operations.

2.4 Revenue model

The developer(s) of a CO₂ pipeline network in Switzerland will require a constant stream of payments to be compensated for their investment as well as for the running costs of such a network. Regarding the payment streams for infrastructure investments in networks, economic theory and regulatory practice distinguish, in general, among the following concepts [9]:

- (i) *Society pays*: subsidies from state or municipal budgets;
- (ii) *Beneficiaries or in this case all industrial emitters pay*: taxes on all emitting industries (that could be channelled to pipeline operations via a fund);
- (iii) *Users of the CO₂ transport network pay*: cost-reflective tariffs for only those emitters who capture and transport CO₂ via the pipeline network;
- (iv) *Other (waste treatment, heat, cement, gas) users pay*: tariffs on waste treatment, cement or gas.

In today's developed energy regulatory frameworks, the 'users pay' model is applied in most EU member states for financing network assets [9]. However, with the Swiss society expected to benefit from climate protection in general and the relevant emitters expected to benefit from the resulting CO₂ savings in particular, the use of a different or hybrid model could be envisioned.

The choice of the revenue model will influence the risks and investing ability of the CO₂ pipeline network and needs to reflect the societal judgement on who should bear the costs for this type of infrastructure. From the financing point of view, ensuring long-term (at least 10-15 years) visibility and security of the revenue stream for the CO₂ pipeline network operator can be seen as one of the most important considerations. In this context, it is also very important to plan how CO₂ pipeline revenues will be linked with the revenue model for the CO₂ capture installations. Given the importance of this link, revenue models for CO₂ capture installations are discussed in more detail.

Revenue and financial support models for CO₂ capture installations

Looking into the research conducted by the Global CCS Institute **Error! Reference source not found.** as well as considering further analysis on this topic, it becomes apparent that, historically, CO₂ capture installations have been financed based on the following:

- (i) *Ability to generate value from CO₂*: by way of enhanced oil recovery ("EOR") use or, in a small number of cases, sale of CO₂ to greenhouses (this reduces/negates climate benefits compared to CO₂ capture and storage ("CCS")),
- (ii) *Government support*: many projects relied on additional upfront capital grants from the government to reduce CAPEX,
- (iii) *Use of low-cost capture opportunities*: for example, the separation of CO₂ gas from methane is standard industry practice in natural gas processing. This substantially reduces projects' capital requirements since the capture facility's costliest component is pre-existing,
- (iv) *Easy access to CO₂ storage or EOR*: the first projects were located close to the few available CO₂ storage or EOR sites.

A large majority of these CO₂ capture installations were developed and financed on the books of state-owned enterprises or of large corporations with experience in gas and oil. This is due to their knowledge of the technologies and practices that underpin CCS and capital availability.



A new wave of CO₂ capture installations outside of the oil and gas industry is being built and financed now in Europe where CO₂ capture is performed strictly for the reasons of climate protection. In order to reach their net-zero goals, many countries are planning to install CO₂ capture on (i) heavy industrial fossil-based CO₂ emitters that are hard to decarbonize, and also on (ii) point sources that emit biogenic CO₂ (e.g., biogas production) with a goal to contribute to national carbon removal goals. These pioneering facilities are defining new standards for operations, technology choices as well as funding and governance mechanisms that are only starting to emerge. To support this crucial pioneering role, most of them are heavily subsidized by the governments, for example:

- EU Innovation Fund has agreed to support four CCS projects in Europe:
 - clean hydrogen production in Porvoo with CCS in the North Sea
 - cement production with CCS in France
 - CCS for hydrogen and chemicals production in Belgium
 - full-scale BECCS in Sweden [11];
- HeidelbergCement is building the world's first full-scale carbon capture facility in Norway at the Brevik cement plant, aiming to capture 400,000 tons annually or 50% of the plant's emissions from 2024 onwards. Project costs of around EUR 421 million will be heavily subsidized by the Norwegian government [13].

Financing CCS at Hafslund Oslo Celsio

Background

- Hafslund Oslo Celsio's waste-to-energy plant in Oslo is Norway's largest with a capacity to end-treat 315,000 tons of waste per year.
- Their CCS project is one of the most mature ones in Europe, with construction starting in July 2022 and formal operations in 2026.
- Targeted capture capacity of 400,000 tons CO₂ per year, which reduces Oslo's emissions by 14% (50% of the waste handled is of biological origin (BECCS)).

Financing structure

- Until recently, Hafslund Oslo Celsio was called Fortum Oslo Varme and was jointly owned by Fortum, the largest electricity retail company in the Nordics, and the City of Oslo (50% each).
- To enable and accelerate the execution of the CCS project, Fortum sold its 50% ownership for approx. EUR 1 billion to a Norwegian investor consortium, resulting in increased 60% ownership by the City of Oslo (via the consortium company Hafslund ECO) and remaining 40% ownership by two investment funds (Infranode and Hitec Vision)**Error! Reference source not found..**

Going forward, such “ad hoc” government support mechanisms are likely to find a more structured format to encourage large-scale adoption of the technology. CCS capture facilities may then become investible based on CO₂ credits, tax savings or the ability to pass on the costs to end customers. Based on currently available incentives, CCS could already be close to profitable to coastal EU emitters within the European Union Emissions Trading System (“EU ETS”) system. However, EU ETS price volatility remains a major challenge, and solutions such as contracts-for-difference are sometimes applied.

In Switzerland, regulatory changes are necessary to make large CO₂ capture projects financeable via regulated compliance markets. As of today, under the Swiss Emissions Trading System (“Swiss ETS”), which is linked to the European Union Emissions Trading System (“EU ETS”), credits are only possible if CO₂ is transported by pipeline or ship. However, for the moment, most Swiss emitters would rely on train or truck transport. In addition, Swiss waste to energy plants and biogenic CO₂ emissions are not included in the Swiss ETS. Another compliance mechanism for CO₂ that could be available in Switzerland is the carbon offsetting mechanism for Swiss motor fuels administered by the



KliK Foundation. However, CCS-based projects are currently not included in the scope of KliK, hence regulatory changes are necessary to enable this pathway **Error! Reference source not found.**

In short, none of the regulated CO₂ credit mechanisms is accessible for CCS projects in Switzerland as these projects include either train- or truck-based CO₂ transport, or work with biogenic CO₂ and/or they are based in the industries outside of the Swiss ETS. In the absence of access to the regulated CO₂ credit markets, CO₂ credits from CCS projects can be sold to the voluntary markets, but they are currently rather small at the required price level.

To receive funding, CO₂ capture projects need to have cash inflows or cash savings that cover the costs and are fixed with reasonable certainty over the long term – at least 10 years although even longer durations would be preferable given the expected lifetime of 20-30 years for CO₂ capture facilities. Long-term agreements between independent projects and public, or strong-credit private

Generic off-take agreement structure

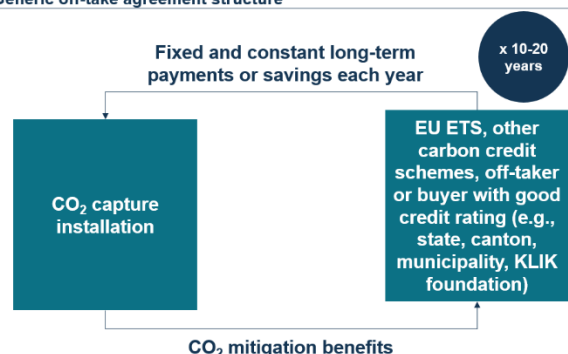


Figure 2: Generic off-take agreement structure

buyers (off-takers), with fixed unit or floor prices, have traditionally been a predominant way to make similar projects “bankable”, as illustrated in Figure . As the CCS sector evolves, investors are expected to become more comfortable with the project risks as well as with the remuneration mechanisms, with the costs of funding such projects going down accordingly, allowing the early movers to re-finance at a better rate.

In Switzerland, different off-take-based compensation schemes may emerge for different sectors (see Figure). For example, plants that capture and store biogenic CO₂ could be compensated by cities, cantons or other emitters who cannot otherwise eliminate their emissions

and need these carbon removal credits to reach their climate goals. On the other hand, fossil-based CO₂ emitters can be compensated via EU ETS, if train and truck transport is included in the new regulations. Fossil-based CO₂ emitters can also possibly pass some of the costs on to their clients. For the emissions by the waste to energy plants, DETEC concluded an agreement with VBSA in March 2022 whereby the operators of waste treatment installations are obliged to put at least one CO₂ capture plant into operation by 2030. The plant is to have a minimum nominal capacity of 100,000 tons of CO₂ per year and capture as much CO₂ as the transport, storage and use conditions permit [17]. Within this context, the cost of CCS may be passed on to the clients for their waste treatment. Additional financial incentives and mechanisms will be necessary to create CCS activity beyond this obligation. In this case, cities and cantons may step in.

Emitters	Type of CO ₂	Potential compensation schemes for CCS
Biogas	▪ Biogenic CO ₂	▪ Some form of compensation for carbon removal or BECCS by, for example, cities or cantons
Waste to energy plants	▪ Biogenic CO ₂ ▪ Fossil-based CO ₂ (around 50%)	
Cement plants	▪ Primarily fossil-based CO ₂	▪ CCS obligation (allowing to charge the cost of CCS to end consumers)
Chemical and other plants		▪ EU ETS (provided that different forms of transport are agreed upon) ▪ Additional mechanisms may be necessary to stabilize EU ETS price volatility

Figure 3: Potential compensation schemes for industrial CCS in Switzerland

Various mechanisms can be used by cities, cantons, or countries to compensate for carbon mitigation via CCS. Some of the emerging structures include:



1. Carbon contracts for difference – a funding mechanism where the government guarantees investors a fixed price that rewards CO₂ emission reductions above the current price levels in the EU ETS or other similar revenues [18]. For example, the Dutch government allocated EUR 2.1 billion to the Porthos CCS project customers [19]. It will be paid over 15 years in grants that come from the Stimulation of Sustainable Energy Production and Climate Transition (“SDE++”) scheme. SDE++ is an operating Dutch subsidy which compensates for the difference between the cost of sustainable energy or the reduction in CO₂ emissions and the revenue, such as EU ETS. The government is expecting the final sum to be lower due to increasing EU ETS prices.
2. Reverse-auction-based funding – where the company with the lowest price per ton removed wins the bid for state-guaranteed long-term offtake and payments. For example, the Swedish government announced an annual USD 46 million state procurement scheme for BECCS [20]. The first reverse auction is to take place in 2022 and deliveries are targeted to commence by 2026.

The chosen mechanisms will influence how quickly different emitters install CO₂ capture and join the CO₂ transport network and should thus be planned in conjunction with the strategy for the CO₂ transport network. In addition, it is important to consider how the compensation mechanisms could be structured in a way that promotes efficient development of the CO₂ pipeline network – i.e., emitters are incentivized to seek lower transport costs instead of just receiving compensation for all incurred expenses.

2.5 Risk management

Investment risk refers to the uncertainty surrounding the investors’ ability to generate the expected returns. Naturally, such a large and novel infrastructure project carries numerous standard project risks for which the financial sector has developed adequate tools and mechanisms which are not the focus of this research project. The main goal is to understand the asset-specific risks that are borne by the fact that it is a pipeline transport infrastructure dedicated to CO₂. A thorough analysis of general CCS project risks has been carried out by the Global CCS Institute **Error! Reference source not found.** (summarised and adapted in Figure), wherein risks are categorized into mitigable risks and risks that are hard to reduce. The hard-to-reduce risks encompass elements, such as (i) regulatory-dependent revenue and stranded asset risks, (ii) cross-chain risks from interdependency of the CCS value chain, and (iii) long-term storage liability and site location risk. For example, the network operator can incur a temporary or even permanent loss of revenues, if the pipelines cannot be operated due to changes in climate policy and lower demand for CCS services, or due to failure in the upstream pipeline in Germany or France or in case of failure or relocation of the storage site. None of these risks are within the control of the network operator in Switzerland and represent huge investment barriers that need to be addressed.

	Description	Examples	Potential solutions (not exhaustive)
Mitigable risks	Risks that can be mitigated through learning by doing. Highest during the first stages of deployment.	! General infrastructure project risks ! Technological and operating risks related to the novelty of the CCS technologies	▪ Developers and operators who have relevant experience ▪ Standard risk mitigation mechanism (insurance, loan guarantees, etc.) ▪ Additional government support for the first projects
Hard-to-reduce risks	Risks that cannot be mitigated in the same way by private sector	! Revenue and stranded asset risks related to the regulatory-dependent value of CO ₂ emissions abatement ! Cross-chain risk from the interdependency of the CCS value chain (several activities, multiple investment decisions, long lead times) ! Long-term storage liability and site location risk (faulty storage site, insufficient capacity, changes in storage location)	▪ Long-term CO₂ policy and pricing visibility and / or committed offtake agreements with individual projects, subsidies, grants ▪ International planning and coordinated actions ▪ Government-level liability assumption and management agreements

Figure 4: An overview of CCS project risks and potential solutions, adapted from [11].



The optimal funding and governance mechanism for the CO₂ pipeline infrastructure may be structured in a way that the risks are allocated to the parties that are most suited to manage them, while additional elements, such as contracts or guarantees, could be used to optimize the funding structure. In addition, it is important to note that a large portion of the potential solutions to the key CO₂ pipeline project risks lies within the control of the government (Figure).

In this case, it is likely that to make the CO₂ transport infrastructure investable, the state or its entities may either need to take a lead investor role or provide investment security mechanisms, such as:

- (i) **long-term contracts** for the purchase of CO₂ transport services at a pre-agreed price or a legal requirement for the emitters to enter such contracts;
- (ii) **guarantees**, or trust funds or insurance mechanisms to be triggered in case of, for example, cross-chain failures or major policy changes;
- (iii) **liability assumption** that could be tapped into in case of major unpredictable events;
- (iv) **investment assistance** by way of upfront grants or tax incentives to reduce the required revenues in the future.

For the mechanism to be most effective, preference could be given to mechanisms that are already known to investors, as they may create less additional uncertainty about how the mechanism would operate in the event of a default.

Considering that the pipeline infrastructure is very capital intensive, the risk of stranded assets requires particular attention during project development. To avoid inefficient utilization or even decommissioning of a pipeline infrastructure or of large parts thereof, both the location and the deployed capacity of potential CO₂ storage sites need to be considered to allow for the captured Swiss CO₂ to be transported in the same direction for at least 20-50 years. Looking at the currently expected CO₂ storage potential in and around Europe (see Figure), a focus on storage activities in the Northern regions of Europe could be expected.

However, several scenarios are conceivable in which the CO₂ storage location changes completely over this long-time horizon – e.g., CO₂ storage becomes available in Switzerland or Italy. While it is impossible to eliminate this risk, a detailed analysis of various future scenarios in network planning could help to minimize the number of stranded pipelines in case of storage location and capacity changes or upstream pipeline default. In addition, the potential for repurposing options for the pipelines for other gases, e.g., hydrogen, could be investigated. Also, bilateral agreements with the respective governments for emissions accounting as well as contracts with the relevant storage providers to guarantee sufficient long-term storage capacity and CO₂ off-take may be desirable but difficult to achieve. Back-up CO₂ storage locations could also be considered and contractually agreed upon prior to the construction of a CO₂ pipeline network.

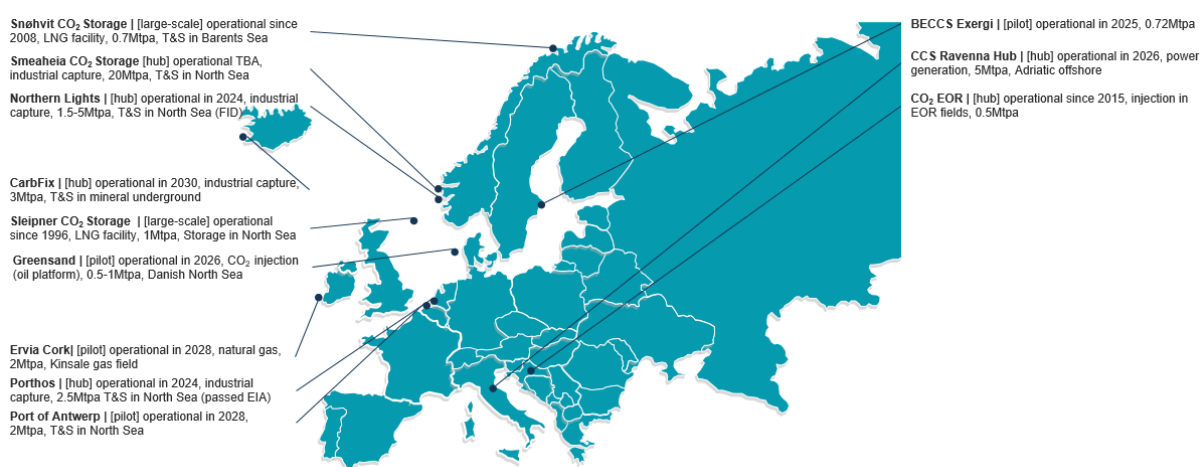


Figure 5: CO₂ storage projects and capacity in Europe, adapted from [21] [22] [23].



Considering private investors, another CO₂ pipeline project-specific element that relates to project risks and long timelines is the fact that typical investors have an investment horizon of 20 years, whereas pipelines have an expected lifetime of around 50-100 years. This could lead to investors having to remain invested for longer than they would prefer and could at the same time lead to a further accentuation of the accompanying investment risks. In similar cases, such as road funding or, for example, the case of a fibre network in Austria, project funding is arranged in such a way that the assets are transferred to the state after 20 years [24]. However, if the asset is transferred to the state after 20 years, investors may require a higher return, because in case of non-performance during the 20-year horizon, they could compensate for lacking returns in years 20-30 (i.e. so-called “*tap into the tail*”).

2.5.1 Cost of capital

The cost of capital refers to a combined (debt and equity) annualized rate of return that investors expect for an investment in a specific project. As pipelines are a very capital-intensive investment, the return that needs to be generated to satisfy the investors constitute a large part of the required operating cash flows each year. To illustrate this with a simple example: if, EUR 3 billion are invested in the pipelines, the network would need to generate around EUR 115 million per year to cover the cost of funding alone assuming a weighted-average cost of capital (“WACC”) of 3.83% that is set for the Swiss electricity provision for 2023 [25], but only around EUR 4.4 million at a WACC of 0.526% which is equivalent to a 20-year Swiss Government Bond yield [26]. At a WACC of around 6.6%, the cost of funding alone would equal the total annual operating cost for the entire network which is estimated to be around EUR 200 million **Error! Reference source not found..** *Note: funding costs here exclude any repayments.*

It is hence not surprising that reducing risks and the cost of funding was found to be key to success in a US model-based study for CCS transport infrastructure roll-out [27], summarised in **Error! Reference source not found..**

Table 1: Summary of the study “Infrastructure to enable deployment of carbon capture, utilization, and storage in the United States”, [27].

	Description
Case study	CO ₂ captured from ethanol bio-refineries (i.e. low-cost CO ₂ capture opportunity) in the Midwest and transported via pipeline infrastructure to the Permian Basin for EOR. Total capture potential of 37 million tons of CO ₂ per year.
Method	A network model that analyses economic feasibility of a pipeline network development given input parameters.
Conclusion	Due to capital intensity of the investment, the system is most sensitive to the cost of finance for the pipeline network (compared to changes in capital requirement and changes in oil price). Lower-cost finance can substantially improve the economic viability of the system.
Findings under different scenarios	Scenario 1: The project is fully financed by government debt at a 3.5% interest rate → Network captures and transports a total of 28.7 Mt of CO ₂ per year from 108 ethanol bio-refinery sources Scenario 2: Half of the capital cost is financed by longer-term government loans (4.5% compared with 6%) → Network captures and transports a total of 19.0 Mt of CO ₂ per year from 63 ethanol bio-refinery sources Scenario 3: The project is fully funded at commercial funding terms at a 6% interest rate



→ Pipeline transport infrastructure funding is non-viable



2.6 Conclusion

Based on the study conducted by Saipem, a scaled-up Swiss CO₂ pipeline network is expected to require CAPEX of approximately EUR 3 billion and OPEX of around EUR 200 million per year **Error! Reference source not found.** While this is not an unprecedented investment in terms of size in Switzerland, the investment carries significant risks, such as (i) regulatory-dependent revenue and stranded asset risks, (ii) cross-chain risks from interdependency of the CCS value chain and (iii) long-term storage liability and site location change risk, that are hard to mitigate. However, it should be considered that a gradual expansion of the pipeline network in several sections – for example, from collection site Basel following the two trunkline routes, could serve as a significant risk-reducing factor, which could be paramount to lowering the cost of private capital. Alternatively, public funding could be considered at favourable Swiss funding rates. Taking a conservative view on the Federal Constitution of the Swiss Confederation **Error! Reference source not found.**, it is assumed that such public funding would be carried out at the cantonal rather than the federal level. The main challenge to be addressed in this case becomes the coordination of actions among the cantons. The development and running of a national CO₂ pipeline network require an organizational and financial model that allows for a certain degree of centralisation among cantons and other funding partners to take strategic decisions that are optimal at the level of the entire system. Furthermore, a method of linking the regulatory-dependent revenue streams of a CO₂ pipeline network with the monetary incentives to operate CO₂ capture plants will be necessary. In the following section, example models of how such an investment could be organised and financed are assessed in the context of three different sets of cases: European CO₂ pipelines, European shared network infrastructure and Swiss shared network infrastructure.

3 CO₂ pipeline funding history and plans in the European context

3.1 CO₂ pipeline funding history

Taking a global perspective, the US has the most mileage of CO₂ transmission pipelines in the world, consisting of approximately 8,300 kilometres of which the vast majority, if not all these CO₂ pipelines, are driven by EOR efforts that increase oil production utilizing CO₂ in a supercritical state [28]. In Europe, the situation is very different. There are only a few CO₂ capture, use and storage (CCUS) facilities in operation, such as the Sleipner and Snøhvit projects in Norway (CCS), Port Jerome hydrogen production in France (CO₂ capture and use, CCU), and the OCAP CO₂ pipeline connecting industrial CO₂ sources with greenhouses in the Netherlands (CCU) [29]. These very localised aforementioned projects include CO₂ pipelines of up to around 150 kilometres that have been financed based on the individual project's business case, pilot learning potential and climate benefits [30] [31] [32].

Developing, financing and governing national, as well as cross-border CO₂ pipeline infrastructure to connect hundreds of CO₂ sources with several CO₂ storage sites or CCU facilities in Europe presents a very different challenge compared to what currently exists in terms of size, complexity and interdependencies. Recent CCS projects already largely rely on a “hubs and clusters” approach to achieve economies of scale and cost reductions and demonstrate increased cooperation between governments and industries as well as cross-border partnerships [33]. For CO₂ transport, this means that more complex networks, including long CO₂ pipelines, are currently already being planned. However, many organizational and financial challenges are still unaddressed and will need to be solved to develop the necessary CO₂ transport infrastructure across Europe as the following cases of Germany, the Netherlands and UK exemplify.



3.2 Planned CO₂ network infrastructure in Germany

OGE, one of the leading European gas transmission system operators, announced that it is planning to build a CO₂ pipeline system that will initially be 1,000 kilometres long and will allow around 18 million tons of CO₂ to be shipped per year [34] (see Figure).



Figure 6: Planned CO₂ transportation grid in Germany [35].

Note: Green lines illustrate the first project stage, grey lines the expected future expansion.

The proposed pipeline network will transport CO₂ for (i) the purposes of re-use, creating a circular CO₂ economy, and (ii) for geological storage. Regarding the creation of a circular CO₂ economy, the intention is to use CO₂ as a carrier for hydrogen forming natural gas (CH₄). Natural gas can be used by the chemical industry in their existing processes and equipment that would otherwise need to be replaced to run with hydrogen. The CO₂ incurring from the utilization processes would in turn be captured again and sent back via a return pipeline to the hydrogen producer to start a new loop. It is also envisioned that some part of CO₂ emitted by the cement, lime and glass production will be sent to the organic chemical industry whose downstream value chains need carbon as a raw material [35]. While the circular loop will only be able to make use of a limited amount of CO₂, it could provide the network with a relatively stable business model that is independent of the success and availability of CO₂ storage operations. However, it remains to be seen how large the income stream from CO₂ recycling in conjunction with hydrogen provision can be. For the CO₂ storage part, various locations are being considered [36].

The key challenge for the project at the moment is the legislative framework in Germany, which does not provide for the right of way for CO₂ pipelines (in contrast to energy carrier pipelines for gas or hydrogen). If this is not solved, the development of a CO₂ pipeline network across Germany may become economically unfeasible. It is also important to note that the project is currently at a relatively early stage of development and many aspects described herein are subject to potential changes in the future.



3.3 Planned CO₂ network infrastructure in the Netherlands

There are several CCUS clusters currently in planning or already in development in the Netherlands. The Porthos project is currently the most advanced and largest CCS project/cluster, collecting CO₂ around the Port of Rotterdam and storing it in empty gas fields in the North Sea. Operations are expected to start in 2024/25. To capture CO₂ from nearby industry, a 30-kilometre pipeline will be laid onshore in an existing pipeline strip along the A15 highway and under the seabed of the North Sea to an empty gas field approximately 20 kilometres off the coast [37]. In June 2021, the Dutch government confirmed the allocation of EUR 2.1 billion in grant funding for Porthos' customers and to remunerate Porthos for the operation of the transport and storage component [38]. This funding under the SDE++ scheme is required to bridge the gap between the current EU ETS rates and the costs involved in carbon capture and storage. Ownership of the transport and storage infrastructure will remain with the operators, which are publicly owned (e.g., EBN and Gasunie, which are wholly owned by the Dutch government, and the Port of Rotterdam Authority, which is owned 50% each by the municipality and the government [39]). Despite currently expected levels of 2.5 million tons of CO₂ being transported per year in the port area, there are plans to build an infrastructure (i.e. pipeline) able to accommodate 10 million tons of CO₂ per year. Given that the SDE++ only remunerates actually stored CO₂, the commercial risk of oversizing infrastructure is absorbed by EBN and Gasunie [39].

In general, two main economic incentives motivate the developments of CCUS clusters in the Netherlands: (i) subsidies under SDE++ scheme whereby the cost of CO₂ reductions (including transport for CCS) that cannot be recovered commercially is covered by the Dutch government with contracts awarded over a period of 12 or 15 years [40] and (ii) a carbon tax/levy that starts at EUR 30 per ton of CO₂ and is set to rise to EUR 125 by 2030 [41].

While this economically-driven approach seems to be successful in motivating cluster formation and development of relatively short pipelines in the Netherlands, it does not seem to provide the right framework conditions for the development of a larger pipeline network. In February 2022, a joint call to action for a strategy on regional CO₂ infrastructure in the Netherlands, Belgium, and North Rhine-Westphalia has been signed by a large group of civil society and private sector stakeholders calling on the national and regional governments to:

- (i) Set up a cross-border CO₂ transport and storage infrastructure working group,
- (ii) Take a leading role in defining the framework conditions for CCS,
- (iii) Develop a common legal framework,
- (iv) Provide the necessary funding framework,
- (v) Acknowledge and standardise the multi-modal and multi-purpose nature of CO₂ transport and storage infrastructure, the deployment of new infrastructure, as well as the retrofitting of existing onshore and offshore infrastructure where this is opportune,
- (vi) Ensure that infrastructure can be expanded to connect to other industrial clusters further inland (for example, in Germany and France) [42].

3.4 Planned CO₂ network infrastructure in the UK

The UK Government has communicated that a new CO₂ transport and storage infrastructure is needed for the use of CCUS which will require an investment of around GBP 15 billion in the early phases, to capture and store around 20-30 million tons of CO₂ per year by 2030 and meet the carbon capture targets specified in the UK's Net Zero Strategy [43]. As a starting point, the CCS Infrastructure Fund of at least GBP 800 million was announced to fund the required infrastructure [44]. It is expected that the rest of the required funding will be sourced primarily from private investors. One company will be appointed to develop and operate the required CO₂ transport and storage infrastructure and will receive financial returns determined under a RAB model. Following several stakeholder consultations in the past years, the UK Government has announced detailed descriptions of the RAB model that is currently being developed and is analysed as a detailed case study in Section 4.2.



3.5 Conclusion

Given the rising national and corporate climate ambitions as well as the development of the first open CO₂ storage locations in Europe, an increasing interest in developing and funding CO₂ pipeline networks in Europe can be seen. Emerging funding structures seem to point to the use of regulated business models as the funding and governance mechanism for such infrastructure in the future. Before RAB regimes are established, monetization of secure long-term contracts with reputable customers seems to be an emerging funding method at this stage. However, it is important to note that the few examples that have been found and described in this section offer quite limited knowledge as they refer to plans and expectations but have not been tested in practice yet. To gain a broader understanding of potential funding and governance models for a CO₂ pipeline infrastructure in Switzerland, the assessed cases outlined above have been complemented with the findings from analysing organizational and financial models for comparable shared network infrastructure investments in Europe and Switzerland in the past.

4 Organizational and financial models for shared network infrastructure

4.1 General overview

Three broad organizational and financial models for large infrastructure projects are distinguished with the following key advantages and key disadvantages [45]:

(i) Government as the main funder, owner, and operator

In this model, the government finances the design and construction of the infrastructure. Although the design and construction can be procured through competitive tenders from private firms, the government owns and operates the asset once construction is completed. This model provides the lowest cost of funding for developed economies (i.e., government bonds) [45]. However, government ownership and operation of infrastructure assets are rarely chosen due to policy preferences for private sector involvement and potential worse price and/or quality outcomes compared with private sector ownership and operation.

(ii) Regulated business models

In the regulated business models, private (or corporatized state-owned) company or companies act as the infrastructure manager: they own, invest in, and operate infrastructure assets. The infrastructure manager charges fees and therefore receives revenue from users and/or subsidies to fund its operations and recoup investment costs. An economic regulator regulates their operations with the goal to incentivize efficient expenditures and affordable tariffs. Relying on joint agreements with the regulator instead of one contract, regulatory business models also offer a certain amount of flexibility during the lifetime of the asset. The Regulated Asset Based (RAB) model is one of the most widely spread regulated business models used for these purposes, although a very high level of variations exists across countries regarding the way it is structured and applied. Overall, in developed economies, the RAB model offers one of the lowest costs of financing, only marginally above that of government bonds [45]. One of the bigger challenges of RAB is incentivising efficient capital expenditures as they can, in large part, be passed on to customers.

(iii) Public-private partnership (PPP) model

In the PPP model, the government calls for tenders for a Design-Build-Finance-Maintain-Operate contract. The contract gives the successful private consortium long-term responsibility for all aspects of design, construction, financing, and operation, including revenue schemes. PPPs are known to be quite efficient in minimizing capital expenditures and delivering in time. However, the cost of financing PPPs is substantially higher than for the RAB model as the responsible private consortium also bears the full risks that are particularly large in such novel projects with significant uncertainty. The PPP contract is also considered to be relatively rigid during the operations phase because the contract, including performance



requirements and potential charges for the full operating period, is usually agreed upon prior to the start of construction. This could be especially tricky for CO₂ infrastructure networks where historic performance levels are not available and there is a lot of uncertainty as to how the future operations and demand will look like from a regulatory point of view.

Note: The distinguishing feature between the models is not the source of the funds, but how the asset is operated once the construction has been completed and, hence, the resulting expected cash flow profile.

Figure provides an overview of how each model addresses key investment characteristics for a Swiss CO₂ pipeline network described under Section 4. Given the rigidity of the PPP model, it does not seem to be well-suited for such a novel and complex investment project. While both the government as an operator and the regulated business models score positively, the fact that government funding for a CO₂ pipeline network at the federal level is unlikely, the rest of the analysis is focused on the regulated business models.

	Government as operator	Regulated business model	Public-private partnership
Investment size	+ Suitable for large infrastructure investments	+ Suitable for large infrastructure investments	~ Suitable for large infrastructure investments with a very well defined operational model
Funders and ownership	+ Government	+ Government or private	+ Government or private
Regulation & coordination	+ High flexibility for regulatory changes + Centralised coordination possible*	+ Relatively high flexibility for regulatory changes + Centralised coordination embedded	- No flexibility for regulatory changes + Centralised coordination possible
Revenue model	+ Flexible	+ Determined in advance but can be changed / adjusted	- Determined in advance and cannot be changed / adjusted
Risk management	+ Government is in a position to control and manage its risks	+ Investor risks are limited	- Relatively high risk for investors
Cost of capital	+ Very low	+ Low	- Relatively high

Figure 7: Overview of organizational and financial models for shared network infrastructure *Needs to be clarified if the Federal Constitution of the Swiss Confederation allows for coordination at the federal level.

Standard project finance transactions have been excluded from the analysis as they are deemed to be only a financial mechanism and our focus is on the models that provide both organizational and financial scope for the development of entire national CO₂ pipeline network. In project finance transactions, a special purpose vehicle is created and financed based on the projected cashflows from the pipeline. Such projected cash flows are backed by long-term purchase contracts with creditworthy counterparts to provide sufficient return certainty to investors. Essentially, it is a way to monetise contracts that can be used as a financing mechanism even under the umbrella of the three organizational and financing mechanisms described above. Project finance has been used in various pre-defined greenfield cross-country gas pipeline developments, such as BTC Pipeline or Nordstream Pipeline [46]. Project finance can also be planned for funding the CO₂ pipeline network irrespectively of whether the RAB model is introduced later by the government or not. In case RAB is never introduced, the private developer would benefit from a natural unregulated monopoly, but they would carry a larger financial risk for the project beyond the contractually secured revenues.



4.2 Regulated business models

Under a regulated business model, a selected infrastructure manager(s), who could be privately or publicly owned, operates an infrastructure asset under the supervision of an independent economic regulator (Figure illustrates the basic structure).

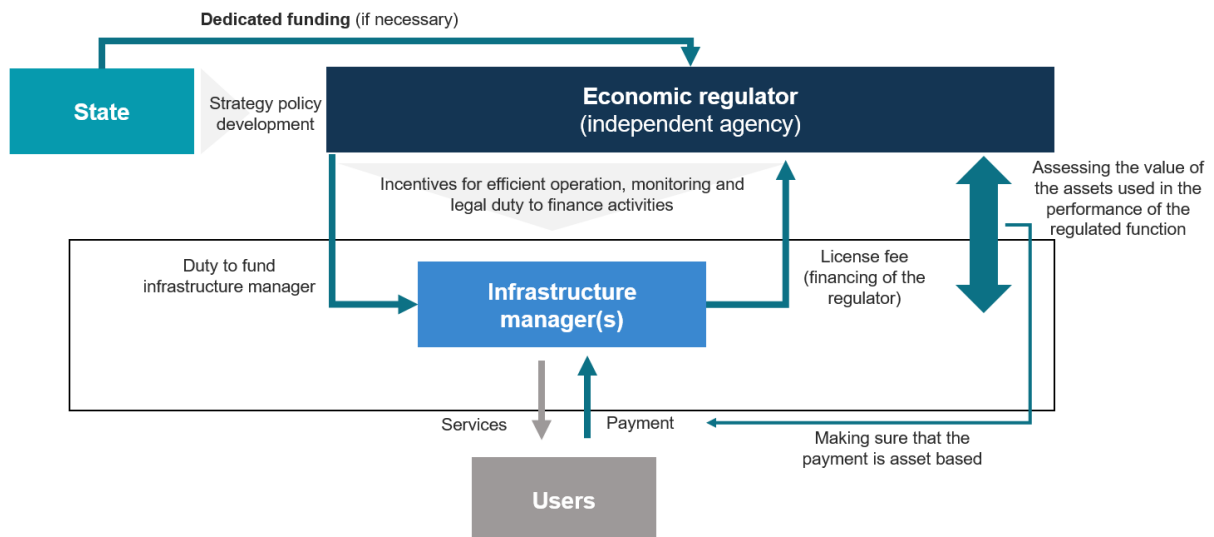


Figure 8: Basic structure of the RAB model, slightly adapted from [45].

The fundamental objective of regulatory business models is to ensure that the operators of an infrastructure are compensated (via charges to end customers) only for their costs to provide a secure and efficient service, and that they are provided with incentives to pursue efficiencies [47]. While a wide diversity exists across regulatory business models, there are two approaches to regulations: (i) Regulated Asset Base (RAB) and (ii) cost-plus. In the past, simple cost-plus regulation was widely used across Europe where regulators allowed power and gas companies to automatically pass through all the costs in their tariffs to customers. Without any incentives to optimise the cost of investments, the system became economically inefficient. Today, the most common regulatory structures across Europe are RAB-based (largely replacing the “cost-plus” approach): they estimate approximately how much money a company has invested and allow to charge a pre-determined return on that investment [48]. The RAB model has many variants and has been adapted to many national contexts. Some countries apply it in combination with the cost-plus approach, some other countries add additional financial performance-based incentives (e.g., to encourage efficient innovation, quality of service or stakeholder involvement), and others cap the allowable income.

Combinations of RAB-like models are currently very widely used as funding and governance mechanisms for transmission infrastructure across Europe. By way of examples – Austria, Belgium, Finland, France, Germany, Ireland, Italy, Netherlands, Spain, and the UK all apply RAB-like funding and governance mechanisms for their electricity and/or gas transmission/transport networks although in several cases, the companies are fully state-owned [49].

The RAB model is also the preferred funding and governance mechanism in several other somewhat more comparable pipeline-based infrastructure projects in Europe. As discussed previously, the RAB model was chosen as the most feasible funding model for the CO₂ transport and storage infrastructure in the UK following a public consultation, where it emerged as a strongly favoured option amongst the consulted parties [50] (for details see UK case study). In addition, a study by Gas for Climate concluded that all the members of their association see the need for an RAB-based system for funding an EU hydrogen network [51].

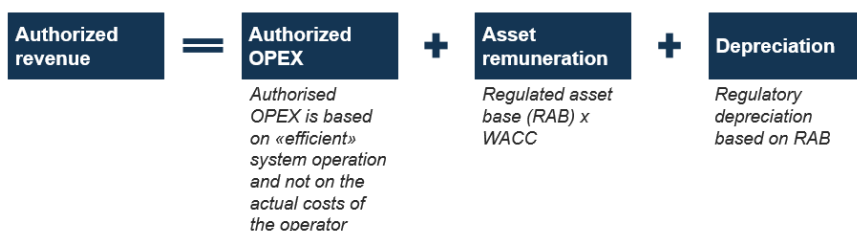


Figure 9: RAB-based regulatory formula for capped revenues [48].

The infrastructure manager under RAB is normally allowed to charge tariffs that amount to the authorised revenue that is defined as the sum of authorised operating expenses (“OPEX”), remuneration for the assets, and depreciation (Figure). Under the cost-plus approach, authorised OPEX equates to the actual expenses incurred whereas the RAB model aims to determine a certain level of OPEX that the operator should incur in case of efficient operations. There are generally two concepts that are used to determine the efficient OPEX [47]:

- **Relative efficiency** – this represents the difference between an operator’s current level of efficiency and that represented by the most efficient operators at a given point in time (defined as those operators lying on the ‘efficiency frontier’);
- **Productivity growth** (“frontier shift”) – this represents the expected movement of the efficiency frontier over time. Even the most efficient operators currently have scope to continue to improve efficiency as innovative technologies and practices become available.

The relative efficiency concept is possibly unlikely to work for a CO₂ transport network because there is neither a historical comparison nor an appropriate peer comparison group for “benchmarking” the costs of operating a large CO₂ pipeline network. Hence, productivity growth or even a cost-based approach with performance-based incentives may be a more reasonable starting point. The revenue model for a CO₂ transport network will also need to be adapted to reflect the fact that the network infrastructure will be in intensive build-up rather than standard operations in the first years – staged regulatory regimes may be necessary along with special incentives for efficient network expansion. Finally, the cross-border nature of CO₂ transport will need to be addressed.

UK RAB plans for CCS infrastructure

The UK Government has communicated their intention to use the RAB model for funding the CO₂ transport and storage network and that they expect the funding to adhere to the following principles:

- **Regulated:** by an independent body to oversee industry and support deployment in line with government policy. Defined in legislation where appropriate.
- **Codification:** the high-level relationship between owners, operators and regulators is clearly articulated.
- **Transparency:** an evidence-based approach leading to well-understood mechanisms/methodologies including revenue calculations. Opportunity for stakeholders to comment, engage and potentially challenge decisions.
- **Stability:** providing a framework for long-term stable investment in a project that is likely to have a long operating life.
- **Adaptability:** given cost uncertainty in the short run any framework will need to include reviews and allow for the possibility of expansion.
- **Equitable risk sharing:** investors to own an appropriate level of risk which is clearly understood and commensurate with returns received by investors. Provision of a fair return to investors over the lifetime of the project [50].



UK RAB plans for CCS infrastructure cont.

System features:

- Operator: **only one licensed company owning both transport and storage network** (onshore and offshore) in order to speed up delivery and to be best placed to negotiate and develop solutions for resolving the commercial and operational interface. Potentially separated in the future.
- Delivery model: **private sector delivery** due to expected speed and cost efficiency, but under a regulatory model and contractual framework with the government.
- Network planning and expansion: initially to be developed at separate clusters, though with the potential for future expansion of clusters into a country-wide network. The operating company is expected to choose the most economically efficient expansion method but the government to make decisions on funding support. First projects and initial overcapacity are potentially subsidized, but CCS is expected to become commercially viable without needing support in the future.

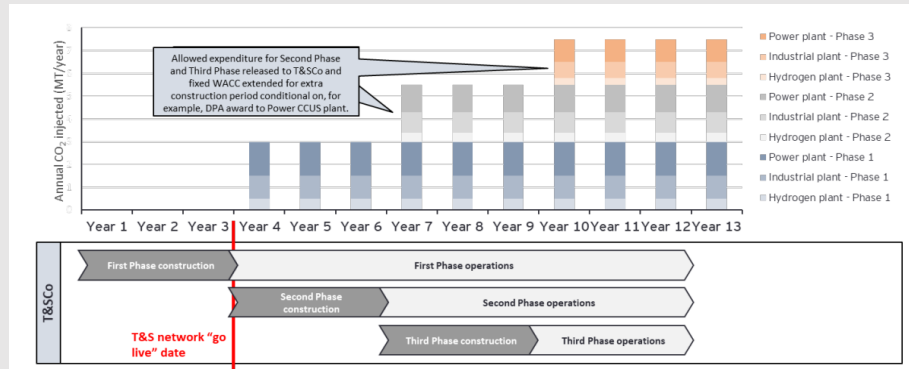
Financial features:

- Revenue model: User pays revenue model. No connection charges in the beginning (new connection costs distributed to all via tariff)
Allowed revenue = (WACC $\times$ Regulated asset value) + Depreciation + OPEX + Decommissioning + Tax + Adjustments
- Incentives for the operator: utilization incentive, availability incentive, minimized leakage incentive, new efficient connection incentive, construction delay penalty
- Revenue risk reduction:
 - Upfront government contribution to reduce required investment and hence required revenues
 - Clauses for cases where revenue could be recovered from taxpayers or users
 - Backloaded depreciation would mean that depreciation increases in line with expected growth in utilization, so that allowed revenue can be reduced in early years and increased in later years
- First mover disadvantage: to solve the problem of higher tariffs in the beginning due to designed overcapacity, upfront financial contributions from the government are anticipated
- Regulatory risk reduction: reopeners (i.e., opportunity to renegotiate long term contract terms) foreseen for regulatory risks
- Additional security: to protect investors from specified remote high impact low probability risks, such as asset stranding or defined leakage events, a contractual arrangement would offer proceeds to investors from a government support package in case of these events being triggered [43] [50] [52] **Error! Reference source not found..**



UK RAB plans for CCS infrastructure cont.

RAB regime is expected to change in each phase of the project delivery plan Error!
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The effectiveness of RAB models depends on the quality of the regulators and regulations underlying the model. As noted earlier, the RAB model may result in challenges with incentivizing efficient capital expenditures given that the costs can normally be passed on to consumers, so this area needs to be very well thought through. In addition, RAB's degree of protection of private investors on asset stranding, particularly over the introduction or widening of competition, has emerged as a problem in various jurisdictions [49].

Careful consideration will also be necessary to adapt the existing regulated business models to fit the case of a CO₂ transport network. Questions on how to determine the authorized OPEX in the absence of "best in class" comparison as well as how to regulate the initial build-up of the network and cross-border collaboration will require detailed consideration and further deliberation. If a regulatory model takes a long time to be established, the first projects could also be funded via, for example:

- (i) Standard project finance or corporate finance for individual transactions under long-term offtake agreements or contractual agreements to bring the project under a regulated business model system;
- (ii) Individual canton, municipality, or city.

4.3 Conclusion

Regulated business models seem to provide the most suitable funding method for a CO₂ transport network by combining low funding costs, incentives for efficient operations and the flexibility to co-evolve with the emergence of the network and with changes in the regulatory environment over time. Figure provides an example of how such a regulated business model structure could look like for a Swiss CO₂ pipeline network. The CO₂ pipeline infrastructure (and, potentially, other auxiliary CO₂ transport infrastructure) could be developed and managed by a separate entity, created specifically for these purposes and owned by the cantons, cities, municipalities and, potentially, some strategic investors, such as pipeline developers, gas distribution network or the emitters themselves. Operations of this infrastructure manager would be regulated by an independent regulator whose responsibility would be to ensure tariff fairness, financial efficiency of the infrastructure manager and, also, alignment of the infrastructure manager's strategy with the Swiss climate policy. The regulator could be created specifically for these purposes or, potentially, an existing regulator could expand its scope to include a CO₂ transport network.

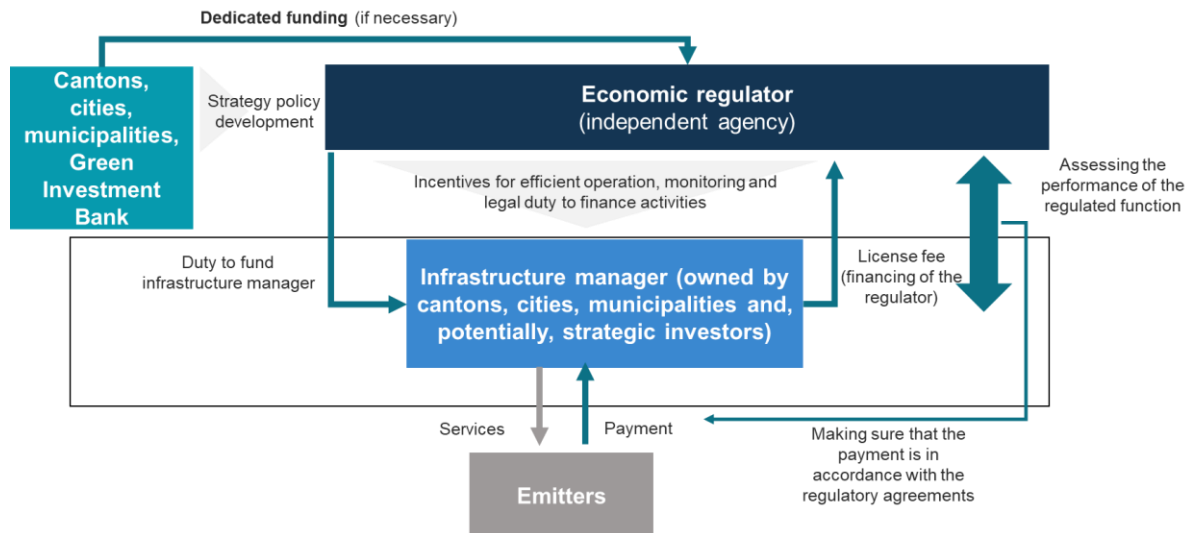


Figure 10: Example of a regulated business model structure for a Swiss CO₂ pipeline network.

5 Organizational and financial models for shared network infrastructure in Switzerland

In this section, organizational and financial models of other shared infrastructure networks in Switzerland, namely electricity grid, gas and water pipelines as well as highways, are assessed. The analysis focuses on the adaptability for a CO₂ pipeline network and whether a regulated business model structure would fit the general policy environment in Switzerland.

5.1 Electricity transmission grid

Electricity is a highly regulated market in Switzerland. As illustrated in Figure , the organizational and financial model for the electricity transmission grid in Switzerland is organized as a form of a regulated business model. As the Swiss transmission system operator, Swissgrid AG is responsible for the transmission of electric power across the country. In accordance with the 2006 Electricity Supply Act (Stromversorgungsgesetz, StromVG, [54]), it is mandated to provide indiscriminatory access to the transmission grid for large end consumers. Its main business activities include control of the transmission grid to ensure stable operation, maintenance, and expansion as well as cooperation with neighbouring countries on grid stability and transmission capacity expansion [55]. Swissgrid is owned by electricity supply companies that are directly or indirectly owned by the cantons [56] and is overseen by an independent regulator – the Federal Electricity Commission (ElCom). ElCom monitors the market, prices, and tariffs, and ensures compliance with the law.

In 2020, the national transmission system operator Swissgrid reported CHF ~3 billion in assets, 59% of which is attributable to the transmission grid (substations and lines) [57]. Its operating costs were CHF 210.6 million in 2020, making it comparatively similar to the envisioned CO₂ transport network, although the assets have most likely been significantly depreciated over the years. As the ultimate ownership of Swissgrid lies with the Swiss cantons, it has a strong credit position. The grid is also a secure asset with long operating history, as well as stable regulation and demand. This security is reflected in the fact that its bonds with a maturity date of 10 years traded at around 1.15% yield in March 2022 [58].

Swissgrid's business model is based on tariffs charged to the electricity distribution system operators for grid usage and ancillary revenue (e.g., pay-as-bid auctions, penalties for non-compliance etc.) received from a virtual aggregation of electricity producers and consumers that have the duty to balance supply and demand of electricity. Ultimately, the costs are passed on to end consumers as the tariffs for distribution system operators and end-consumers are based on the chargeable cost, calculated from the "cost-plus" regulation [55].

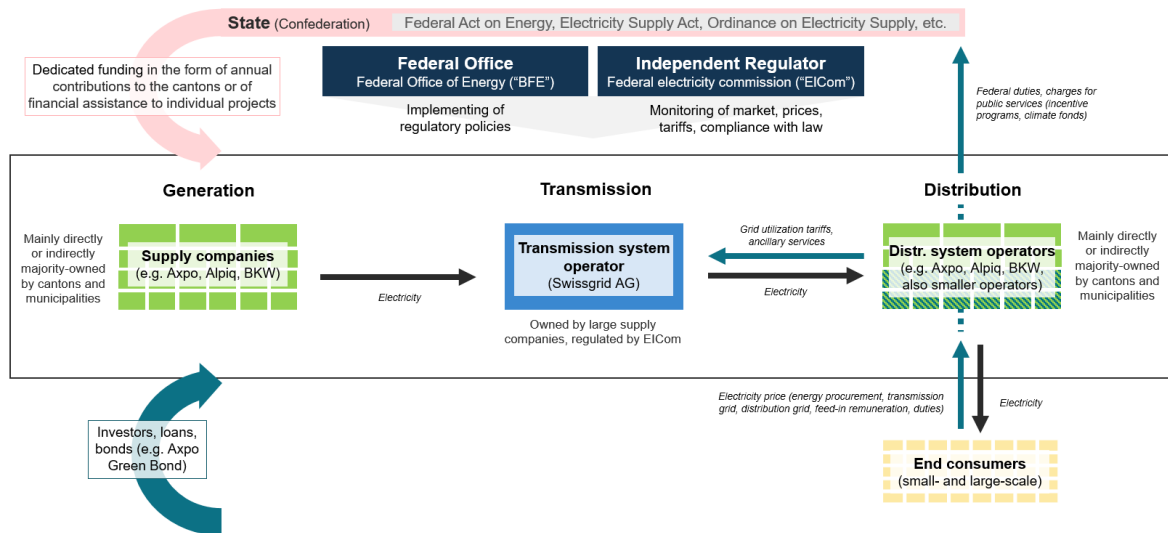


Figure 11: Overview of the organizational and financial model for the electricity transmission grid in Switzerland.

Table 2: Key organizational and financial characteristics of the Swiss electricity transmission grid.

	Description
Investment needs	- In 2020, the national transmission system operator Swissgrid reported CHF ~3 billion in assets and the transmission grid (substations and lines) accounts for 59% of that. - Net turnover of CHF 588 million was reported compared to operating costs of CHF 210.6 million [57].
Funders and ownership	Through its shareholders (BKW Netzbeteiligung AG, Axpo Power AG, Axpo Solutions AG, EKZ, SIRESO SA, Centralschweizerische Kraftwerke AG and others) Swissgrid is almost completely owned by the Swiss cantons [56].
Regulation and coordination	- Electricity is a highly regulated market in Switzerland. The 2006 Electricity Supply Act (Stromversorgungsgesetz, StromVG) unbundles the vertically integrated electricity supply chain. It mandates indiscriminatory access to the transmission grid for large end consumers. - Ownership was centralized within Swissgrid due to the high level of investment in the construction of the transmission grid, the rising economies of scale (and declining marginal costs), and due to high irreversible costs [56]. - Swissgrid is overseen by ElCom.
Revenue model	- Swissgrid's business model is based on tariffs charged to the electricity distribution system operators for grid usage and dealings (e.g., pay-as-bid auctions, penalties for non-compliance etc.) with a virtual aggregation of electricity producers and consumers that have to balance supply and demand of electricity. - The tariffs for distribution system operators and end-consumers are based on the chargeable cost, calculated from the "cost-plus" regulation. Ultimately, the costs are passed on to end consumers [55].
Risk management	- As the ultimate ownership of Swissgrid lies with the Swiss cantons, it has a strong financial position. - The grid is also a secure asset with long operating history, as well as stable regulation and demand.



Cost of capital

- 10-year bonds for Swissgrid traded at around 1.15% yield in March 2022 [58].
- Industry WACC for 2023 was set at 3.83% in accordance with the Electricity Supply Act by DETEC [25].

Historically, construction of the Swiss transmission grid was mostly driven by cantonal electric utilities before ownership was centralized within Swissgrid (see Figure). The main reasons for centralizing ownership were high levels of investment in the construction of the transmission grid, rising economies of scale (and declining marginal costs) and high irreversible costs [56].

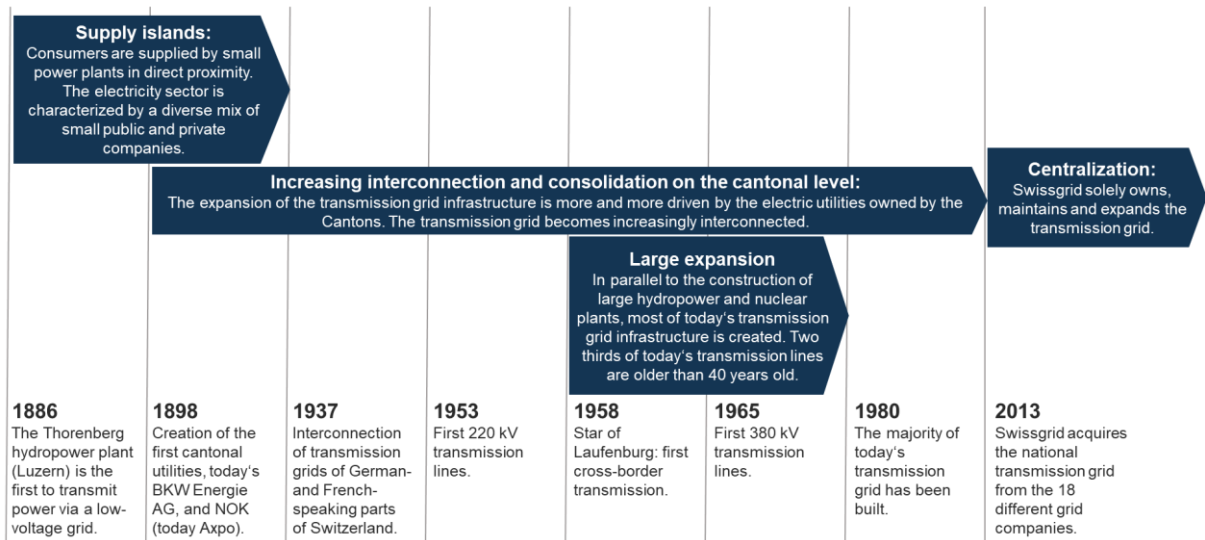


Figure 12: Historic developments in the build-up of the electricity transmission grid in Switzerland [59].

Swissgrid is also part of the European Network of Transmission System Operators (ENTSO-E), which coordinates cross-border transmission and grid development (see Figure). This provides an interesting example of how to organize cross-border CO₂ transport.

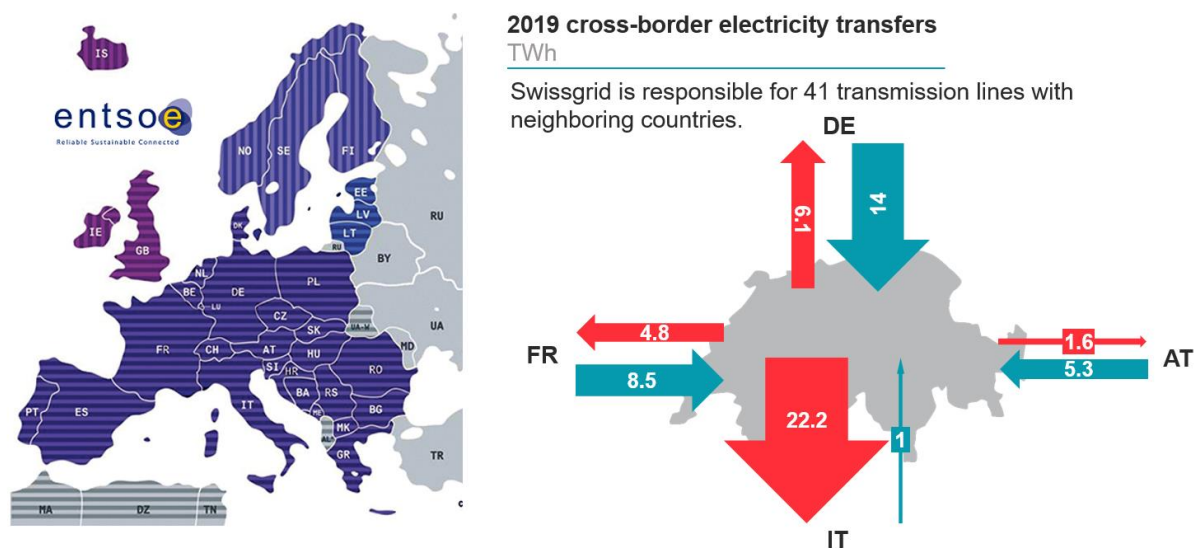


Figure 13: ENTSO-E and cross-border electricity transfers [55] [60].



Overall, the Swiss organizational and financial model for the electricity grid seems to be a suitable example to follow for a national CO₂ pipeline network given its capacity to enable centralized decision-making, relatively low funding costs as well as a regulatory mechanism to incentivize cost efficiency. The cost-plus rather than asset-based pricing approach could also be applied in a case of CO₂ pipeline network given the lack of historical data on efficient performance for such networks. If a regulated business model is chosen, potentially, an existing regulator could be used to build on the knowledge that has been collected so far and increase the speed of legislative development.

5.2 Natural gas pipelines

In general, Switzerland does not have a specific regulatory framework for the production and no comprehensive framework governing the import, storage, transport, and distribution of natural gas. Swissgas AG (majority-owned by four large regional supply companies, e.g., Erdgas Ostschweiz AG), transports gas from abroad to the four large regional supply companies on a non-profit basis and safeguards industry interests in Switzerland and abroad. Four large regional supply companies – Erdgas Ostschweiz AG, Erdgas Zentralschweiz AG, Gasverbund Mittelland AG and Gaznat SA – procure and transport gas to smaller local supply companies on a non-profit basis, and sometimes directly sell gas to end consumers (see Figure).

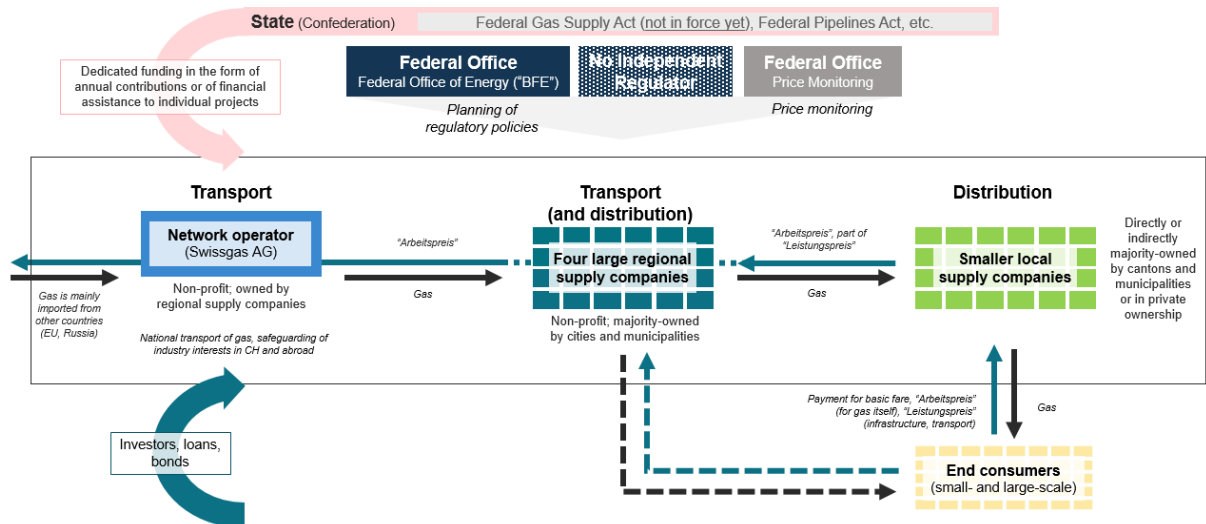


Figure 14: Overview of the organizational and financial model for natural gas pipelines in Switzerland.

Swissgas AG is responsible and owner of 260 kilometres high-pressure pipelines that are interregional [61]. However, the majority of the Swiss gas pipeline grid is owned and operated by the supply companies. The four regional supply companies are mainly publicly owned, and so are the pipelines they run. Owners of the pipelines are users of the pipelines with some exchange of services at an agreed-upon price. According to the Federal Pipelines Act of 1963, they have an obligation to transport gas if technically and economically feasible and if a third party provides appropriate compensation [62].

The system can largely be described as a "territorial monopoly" where regional supply companies have a secure customer base and costs can be directly passed on. Yearly investments into the gas grid can differ strongly but usually range between CHF 140 and 190 million [63]. Today, there is still no standard legal framework to ensure effective competition in Switzerland. The first draft of the Federal Gas Supply Act from 2019 aims to:

- (i) Create pressure from the regulatory side (price monitoring, tariff reductions, prohibited tariff increases);
- (ii) Provide clearer rules to facilitate the development and unbundling of an efficient gas market in Switzerland [64].



Table 3: Key organizational and financial characteristics of the Swiss gas pipeline network.

Description	
Investment needs	• Only 260 kilometres of the Swiss gas pipeline grid are owned by Swissgas AG [61]. • Yearly investments into the gas grid can differ strongly but usually range between CHF 140 and 190 million [63].
Funders and ownership	• Swissgas AG and the 4 large regional supply companies own the main interregional, high-pressure pipelines. Swissgas AG itself is owned by the 4 regional suppliers and they are mainly publicly owned. It is their responsibility to supply the local gas suppliers with gas and allow them connection to the main grid.
Regulation and coordination	• In general, Switzerland does not have a specific regulatory framework regulating gas production and no comprehensive framework governing the import, storage, transport, and distribution. Federal Pipelines Act of 1963 obliges to transport gas if technically and economically feasible and if third party provides appropriate compensation [62]. • 2019 first draft of Federal Gas Supply Act (“GasVG” – not in force yet) would introduce pressure from the regulatory side (price monitoring, tariff reductions, prohibited tariff increases) [64].
Revenue model	• Owners of the pipelines are users of the pipelines with some exchange of services at an agreed upon price.
Risk management	• Industry works as a “territorial monopoly” in large parts of Swiss gas market where four large regional supply companies have a secure customer base, long pipeline operating track record, long-term supply agreements and costs that can be directly passed on, making it relatively secure from a risk point of view. • However, a decay of trade prices has been observed in recent years, and “net zero” will trigger further critical questions for the industry, hence increasing the risks.
Cost of capital	• Industry WACC for 2021 was set at 5.15% [64].

Overall, the organizational and financial model for the Swiss gas pipelines appears to be less suitable to a national CO₂ pipeline network compared to the model for the electricity grid as it seems to be less fitting for nationally centralised decision-making and has somewhat higher funding costs due to higher inherent risks in the gas pipeline infrastructure.

5.3 Water infrastructure

In Switzerland, the municipalities are responsible for the water supply. They pay concessions to the cantons to use the water. The water supply infrastructure is therefore owned and maintained by the municipalities, as illustrated in Figure . In total, the Swiss water supply network amounts to 80,000 kilometres in length with investments of around CHF 50 billion so far. Sustaining the installed infrastructure costs about CHF 800 million each year [66].

The costs of sustaining the installed infrastructure are paid by the municipalities and passed on to the consumers. All costs are financed by the user fees (households, industry etc.). However, it is defined by law that water suppliers are not allowed to generate profit and therefore the fees should only cover the costs **Error! Reference source not found.** The final cost of water (i.e., water tariffs) is the sum of yearly fixed costs and variable costs per cubic meter consumed. There is a price supervisor that makes sure that all price changes are justified. The price for water differs between municipalities since



the cost of supply depends on the availability and the source (e.g., a mountain well is a cheaper water source than a deep well that requires pumping of water).

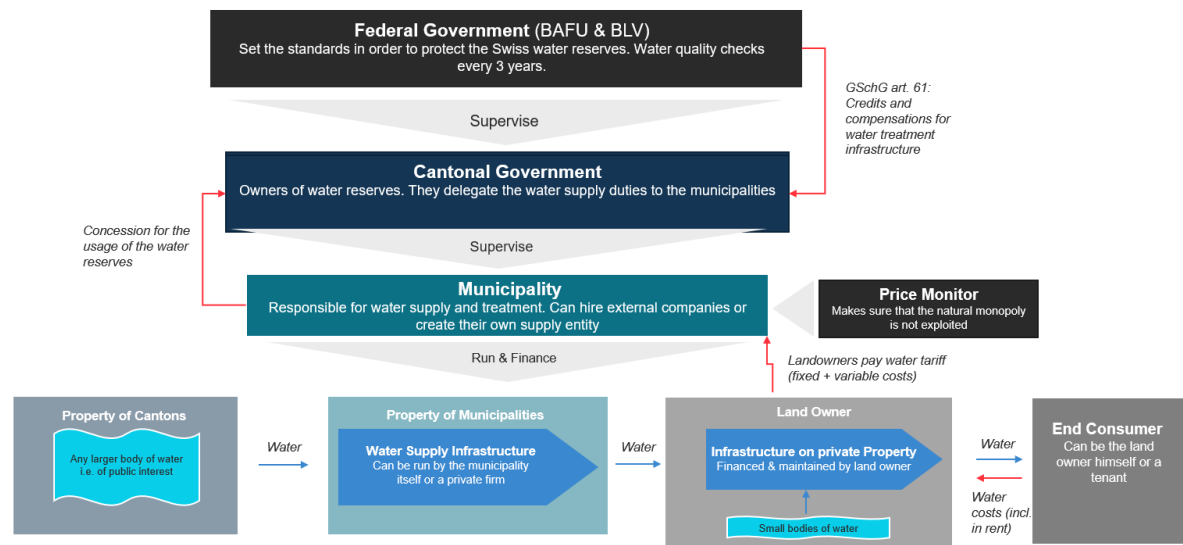


Figure 15: Overview of the organizational and financial model for the water supply network in Switzerland.

Table 4: Key organizational and financial characteristics of the Swiss water supply network.

Description	
Investment needs	- In total, the Swiss water supply network amounts to 80,000 kilometres in length and CHF 50 billion have already been invested. - Sustaining the installed infrastructure costs about CHF 800 million each year [66].
Funders and ownership	- The municipalities are responsible for the water supply. They pay concessions to the cantons to use the water. The water supply infrastructure is therefore owned and maintained by the municipalities. - The costs of sustaining the installed infrastructure is paid by the municipalities and the costs are passed on to the consumers.
Regulation and coordination	- Regulation: On a federal level the «Gewässerschutzgesetz» and «Gewässerschutzverordnung» are the main framework. Cantonal and communal regulations can complement the national law. - Municipalities have a lot of freedom in deciding how they invest. It can happen that smaller municipalities cooperate to fund the network and increase its resilience.
Revenue model	- All costs are financed by the user fees (households, industry etc.). However, it is defined by law that the water suppliers are not allowed to generate profit [67]. The final cost of water (i.e., water tariffs) is the sum of yearly fixed costs and variable costs per cubic meter consumed. - The price for water differs between municipalities, since the cost of supply depends on the availability and the source (e.g., a mountain well is a cheaper water source than a deep well that requires pumping of water). there is a price supervisor that makes sure that all price changes are justified.



Risk management	Water supply network presents minimal risks to the investors as it is a long-standing infrastructure with long operational track record and a relatively stable demand as well as predictable pricing and regulatory policy.
Cost of capital	If the water supply is categorized as a “special financing” of the municipality, only the costs of the required debt capital is charged. No interest is paid on equity capital because equity capital is based on surplus and therefore is not really provided by the community [67].

As the water supply network is very localized and there are only a few instances where cooperation across cantons or municipalities is necessary, its funding and governance model is probably not the most suitable one for a national CO₂ transport network in Switzerland.

5.4 Highways

In Switzerland, highways are almost exclusively run and owned by the federal government with a few exceptions where cantons with high traffic density require additional capacity and construct their own highways. For national roads, all planning and supervision responsibilities lie with ASTRA, which is the federal office for roads in Switzerland. They ensure a functioning and secure network throughout Switzerland and determine the need for expansion of the highways. Similar authorities can be found both on a cantonal and communal level (see Figure).

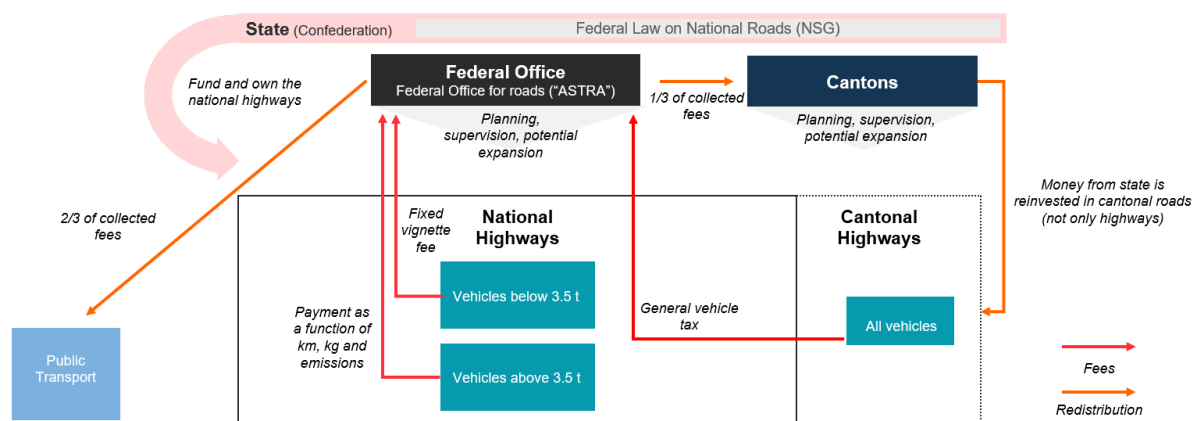


Figure 16: Overview of the organizational and financial model for the highway network in Switzerland.

In 2019, the infrastructure for motorized traffic cost the public office CHF 8.1 billion. To use a Swiss highway, a toll has to be paid. Generated income from motorized traffic for the government in 2019 was 8.7 billion (51% tax on fuel and 28% from cantonal vehicle taxes, the rest is “Leistungsabhängige Schwerverkehrsabgabe” (“LSVA”) and vignette). Therefore, the cost covering of road infrastructure is 107% [68]. Two thirds of these revenues flow into the funding of public transport, while the cantons receive one-third for the maintenance of their roads [69].

Table 5: Key organizational and financial characteristics of the Swiss gas pipeline network.

Description	
Investment needs	In 2019 the infrastructure for motorized traffic cost the public office CHF 8.1 billion. These costs are distributed evenly: 35% national roads, 31% cantonal roads and 34% communal [68].
Funders and ownership	Highways are almost exclusively run and owned by the federal government. There are exceptions where cantons with high traffic density require



	additional capacity and construct their own highways. • The “national road network” includes all the roads that are run and funded by the federal government, and they also include larger roads that are not necessarily highways.
Regulation and coordination	• For national roads, the authority lies with ASTRA, which is the federal office for roads in Switzerland. They ensure a functioning and secure network throughout Switzerland. • All planning and supervision responsibilities lie with ASTRA, meaning they also determine the need where to expand the highways. Similar authorities can be found both on a cantonal and communal level.
Revenue model	• To use a Swiss highway a toll must be paid. For passenger vehicles this is done by buying a 40 CHF vignette which allows the unlimited use of the highways for a year. Vehicles above a weight of 3.5 tons however must pay the LSVA. This fee depends on the amount of kilometres driven, the weight of the vehicle and the emission class. Additionally, it does not only apply to highways, but all roads. • Generated income from all motorized traffic is CHF 8.7 billion (51% tax on fuel, 28% cantonal vehicle taxes and 21% LSVA/vignette) [68]. 2/3 of this goes into funding public transport and 1/3 goes to the cantons to sustain their roads [69]. • Currently, motorised traffic infrastructure in Switzerland covers its own expenses for construction and maintenance (excluding costs of transport, environmental and health costs, and costs for private roads).
Risk management	• It is a secure infrastructure where the fees reflect the costs.
Cost of capital	• The investments in road infrastructure are federal assets and are funded at the cost of funding for Switzerland.

Overall, the organizational and financial model for highway funding in Switzerland provides a way to centralise planning and running decisions, has low funding costs and covers its own costs, which suggest that it could be a suitable example to follow for the CO₂ pipeline network. However, the question of whether a CO₂ pipeline network can be organised and funded at a federal level needs to be addressed.

5.5 Conclusion

Overall, a high degree of direct or indirect public ownership at cantonal and municipal level is exhibited by the Swiss shared network infrastructures analysed herein. Also, a trend towards centralization and regulation over time can be noticed in the case of the electricity grid and of the gas pipeline infrastructure. In general, these observations point to the fact that a regulated business model approach observed as emerging in Europe for national CO₂ pipeline networks could also work in the Swiss political context as the Swiss electricity grid, in particular, is already organised in such a way.

Individually, the funding and governance models for the Swiss electricity grid and highways arguably offer the most potential to draw conclusions for a CO₂ infrastructure build-up as they contain a centralised way to plan and supervise the development of the network. However, the model for highways is executed at the federal level, which may not be possible in case of CO₂ pipelines given the current Swiss Federal Constitution. If a regulated business model is chosen, potentially, an existing regulator could be used to build on the knowledge that has been collected so far and increase the speed of legislative development.



6 Evaluation of results to date and outlook

The topic of organizational and financial models for future CO₂ pipeline infrastructure in Switzerland is very new and unexplored in both academia and practice and neither organizational nor financial models have yet been proposed for Switzerland. At the same time, emerging organizational and financial models for CO₂ pipeline networks in Europe as well as existing models for other shared network infrastructure in Europe and Switzerland offer a lot of models and approaches, from which a lot can be learnt. In this context, this report provides an extensive overview of potential organizational and financial models for CO₂ pipeline networks in Switzerland and serves as a starting point for further in-depth analysis.

A scaled-up Swiss CO₂ pipeline network is expected to require CAPEX between EUR 2.7 and 3.1 billion and to have OPEX of around EUR 200 million per year **Error! Reference source not found.** While this is by no means an unprecedented investment in terms of size in Switzerland, the investment carries significant risks, requires concerted organizational efforts from a large number of players in Switzerland as well as abroad and is dependent on having low cost of capital. Therefore, it should be considered that a gradual expansion of the pipeline network in several sections – for example, from collection site Basel following the two trunkline routes, could serve as a significant risk-reducing factor, which could be paramount to lowering the cost of private capital. At the same time, public funding could be used at the favourable Swiss funding rates. Taking a conservative view on the Federal Constitution of the Swiss Confederation **Error! Reference source not found.**, it is assumed that such public funding would be carried out at the cantonal rather than at the federal level, but legal opinions are necessary to clarify this matter. If it is indeed the case, the main challenge to be addressed becomes coordination of actions and funding among the cantons.

To understand how such an investment could be organised and financed, irrespective of the funders, this report looks into three different groups of cases: European CO₂ pipelines, European shared network infrastructure and Swiss shared network infrastructure. Overall, regulated business models with a central operating entity seem to provide the most suitable funding approach for a Swiss CO₂ pipeline network by combining low funding costs, incentives for efficient operations and the flexibility to co-evolve with the emergence of the network and with changes in the regulatory environment over time. However, careful consideration will be necessary to adapt the existing regulated business models to fit the case of a CO₂ transport network. Questions on how to determine the authorized OPEX in the absence of “best in class” comparison as well as how to regulate the initial build-up of the network and cross-border collaboration will require detailed deliberation. Existing organizational and regulatory bodies and structures, such as ElCom or ASTRA in Switzerland can be consulted and their expertise exploited. Before regulatory regimes are established, monetization of secure long-term contracts with reputable customers seems to be an emerging funding method at this stage and could also be used in Switzerland.

Additional research will also be necessary to answer many questions that are emerging at this stage:

- Who should set up the necessary organizational and financial structure for the CO₂ pipeline network in Switzerland?
- How can different revenue models for CO₂ capture installations be used to incentivise optimal pipeline development?
- How can the risk of stranded assets be best minimized – e.g., modelling of various scenarios and search of asset repurposing options?
- How can the funding and governance of the CO₂ transport infrastructure be organized internationally? What bodies will be necessary for coordination at the EU level?

This subtask will serve as a basis for the detailed academic research in “*Subtask 2.1 - Investment and financing needs along the supply chain of CCS and CCU*” and “*Subtask 2.2 - Effective support policy designs for mobilization of CCS and CCU finance*”. Subtask 2.1 in particular builds on the potential financing options identified in this report and applies them to pipelines and other modes of transportation (trains, trucks, ships, pipelines). As part of the subtask, the researchers then analyse how these different financing options affect the cost of capital of transport assets and what the implications are for the overall cost of carbon transport.



In addition, this analysis exploits synergies with the H2020 EU Project "ACCSESS", where organizational and financial models for a CO₂ network infrastructure in the broader European context are being investigated.



Abbreviations

ASTRA: Swiss Federal Roads Office

BECCS: Bioenergy with carbon capture and storage

CAPEX: Capital expenses

CCS: CO₂ capture and storage

CCU: CO₂ capture and usage

CCUS: CO₂ capture, usage and storage

CCTS: CO₂ capture, transport and storage

EICom: Federal Electricity Commission

ENTSOE-E: European Network of Transmission System Operators

EOR: Enhanced oil recovery

EU ETS: European Union Emissions Trading System

LSVA: Leistungsabhängige Schwerverkehrsabgabe

Mtpa: Million tons per annum

OPEX: Operating expenses

PPP: Public-private partnership

RAB: Regulatory asset base

SDE++: Stimulation of Sustainable Energy Production and Climate Transition

Swiss ETS: Swiss Emissions Trading System

T&S: Transport and storage

VBSA: Swiss Association of Waste Treatment Plant Operators

WACC: weighted average cost of capital



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