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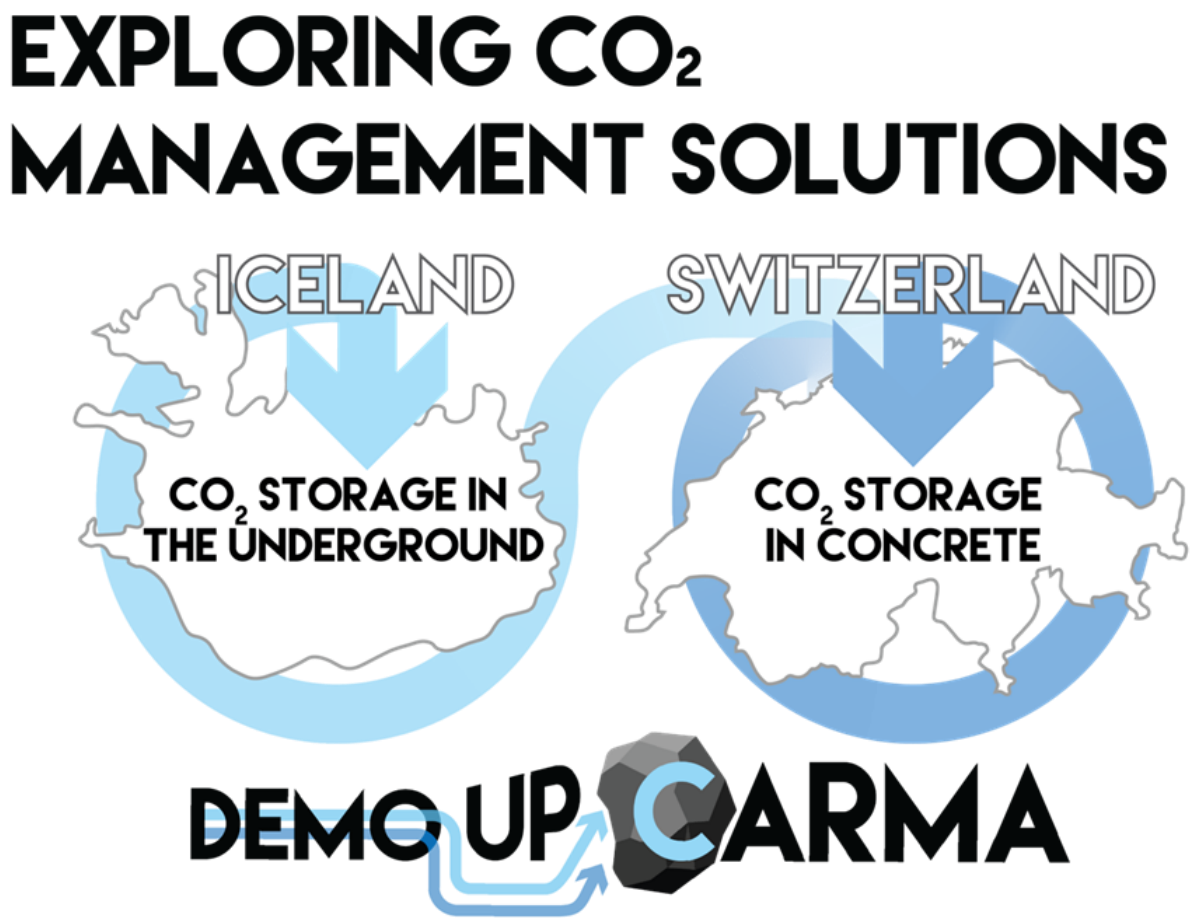
Final report dated 15 December 2023

DemoUpCARMA

WP5 Final Report



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The authors bear the entire responsibility for the content of this report and the conclusions drawn therefrom.

Zusammenfassung

Work Package (WP) 5 von DemoUpCARMA untersucht politische, regulatorische, finanzielle und Akzeptanz-Aspekte von CCTS/CCUS-Wertschöpfungsketten und identifiziert potenzielle Lücken für ihre Umsetzung und Skalierung. Zu diesem Zweck umfasst dieses WP eine Analyse der Klimafinanzierungsinstrumente auf nationaler und internationaler Ebene, eine Untersuchung effektiver politischer Konzepte zur Überwindung von Finanzierungs- und potenziellen Akzeptanzproblemen, eine Analyse der Interessengruppen und Vorschläge für eine angemessene Kommunikation sowie eine Bewertung technischer und organisatorischer Fragestellungen im Zusammenhang mit dem Ausbau der erforderlichen Infrastruktur.

Aufgrund der Neuartigkeit der DemoUpCARMA-Pilotdemonstrationen sowie der CCTS/CCUS-Wertschöpfungsketten und ihrer politischen, regulatorischen, finanziellen und Akzeptanz-Aspekte insgesamt wurde eine Reihe qualitativer und explorativer Methoden angewandt, um sich den anstehenden Themen zu nähern; dazu gehörten beispielsweise eine Bestandsaufnahme und Kartierung bestehender nationaler und internationaler Best Practices sowie Workshops und Interviews mit relevanten Schlüsselakteuren (wie nationalen Behörden, Industriepartnern, Fachexperten, der Öffentlichkeit, Verbänden und Unternehmen aus vergleichbaren Branchen usw.).

Während die Schweiz CCTS/CCUS in ihrer langfristigen Strategie zur Erreichung von Netto-Null-Emissionen bis Mitte des Jahrhunderts eine bedeutende Rolle zugewiesen hat, haben die CCTS/CCUS-Wertschöpfungsketten aufgrund der damit verbundenen hohen Kosten und unzureichenden Investitionsrenditen derzeit keinen tragfähigen Business Case. Um wirtschaftlich tragfähig zu werden, werden diese Technologien voraussichtlich weitere wirtschaftliche Anreize benötigen. Zu diesem Zweck wurde eine Analyse aktueller und potenzieller künftiger Klimafinanzierungsinstrumente auf nationaler und internationaler Ebene in der Schweiz und in anderen Ländern sowie ihres Potenzials für die Mobilisierung und Verbreitung von CCTS/CCUS-basierten Klimaschutzmethoden durchgeführt. In der Schweiz und weltweit wurden mehrere Initiativen zur Unterstützung von CCTS/CCUS-Aktivitäten auf den identifiziert, darunter Kohlenstoff-Differenzverträge, steuerliche Anreize oder Kaufverträge verschiedener Art. Als Ergebnis dieser Zusammenstellung wurden mehrere Möglichkeiten für Interessengruppen identifiziert, Massnahmen zu ergreifen und dazu beizutragen, bestehende Herausforderungen zu bewältigen und die Verbreitung von CCTS/CCUS-Lösungen weiter voranzutreiben.

Bei der Kartierung der Stakeholder entlang der CCTS/CCUS-Wertschöpfungsketten wurden Stakeholder aus Wissenschaft, Wirtschaft, Politik und Zivilgesellschaft sowie der Öffentlichkeit identifiziert. Faktoren mit potenziell positiven, negativen oder ambivalenten Auswirkungen auf die Wahrnehmung von CCTS/CCUS durch die Stakeholder wurden untersucht. Darüber hinaus wurden in Interviews mit relevanten Akteuren in Island aus Verwaltung, Politik, Industrie, Wissenschaft und Gesellschaft deren Ansichten zu grenzüberschreitenden CCTS mit geologischer Speicherung in Island erfragt.

Was die organisatorischen und finanziellen Modelle betrifft, die für eine CO_2-Pipeline-Netzinfrastruktur in der Schweiz in Frage kommen, wurde ein umfassender Überblick über mögliche Modelle erstellt. Insgesamt scheinen regulierte Geschäftsmodelle mit einem zentralen Operator den am besten geeigneten Finanzierungsansatz für ein Schweizer CO_2-Pipelinenetz zu bieten, da sie niedrige Finanzierungskosten, Anreize für einen effizienten Betrieb und die Flexibilität bieten, sich mit der Entstehung des Netzes und mit Änderungen des regulatorischen Umfelds im Laufe der Zeit mitzuentwickeln.

Résumé

Le module de travail 5 de DemoUpCARMA évalue les aspects politiques, réglementaires, financiers et d'acceptation des chaînes de valeur CCTS/CCUS et identifie les lacunes potentielles pour leur mise en œuvre et leur mise à l'échelle. À cette fin, ce paquet de travail comprend une analyse des instruments de financement du climat aux niveaux national et international, une enquête sur les conceptions politiques efficaces pour surmonter les défis de financement ainsi que l'acceptation potentielle du public, une analyse des parties prenantes et des suggestions pour une communication appropriée, et une évaluation des questions techniques et organisationnelles concernant la mise à l'échelle de l'infrastructure de transport nécessaire.

En raison de la nouveauté des démonstrations pilotes de DemoUpCARMA ainsi que des chaînes de valeur CCTS/CCUS et de leurs aspects politiques, réglementaires, financiers et d'acceptation dans l'ensemble, une gamme de méthodologies qualitatives et exploratoires a été appliquée pour aborder les sujets à portée de main ; ceux-ci comprennent par exemple un inventaire et une cartographie des meilleures pratiques nationales et internationales existantes, des ateliers et des entretiens avec les principales parties prenantes (telles que les autorités nationales, les partenaires industriels, les experts en la matière, le public, les associations et les entreprises des industries comparables, etc.).

Bien que la Suisse ait attribué au CCTS/CCUS un rôle de premier plan dans sa stratégie à long terme visant à atteindre des émissions nettes de GES nulles d'ici le milieu du siècle, les chaînes de valeur CCTS/CCUS ne présentent pas actuellement d'analyse de rentabilité viable en raison des coûts élevés et des retours sur investissement insuffisants qui y sont associés. Pour devenir économiquement viables, ces technologies auront probablement besoin de nouvelles incitations économiques. À cette fin, une analyse des instruments de financement climatique actuels et potentiels au niveau national et international, en Suisse et dans d'autres juridictions, et de leur potentiel pour mobiliser et développer les méthodes d'atténuation basées sur le CCTS/CCUS a été réalisée. Plusieurs initiatives ont été identifiées en Suisse et dans le monde pour soutenir les activités du CCTS/CCUS sur les marchés du carbone volontaires et de conformité, y compris les contrats carbones pour la différence, les incitations fiscales ou les accords d'achat de différents types. Cette évaluation du paysage a permis d'identifier plusieurs possibilités pour les parties prenantes de prendre des mesures et de contribuer à relever les défis existants et à intensifier le déploiement des solutions CCTS/CCUS.

Comme pour la cartographie des parties prenantes le long des chaînes de valeur CCTS/CCUS, des acteurs du monde scientifique, des affaires, de la politique, de la société civile et du public ont été identifiés. Les facteurs susceptibles d'avoir un impact positif, négatif ou ambivalent sur la perception des CCTS/CCUS par les parties prenantes ont été évalués. En outre, des entretiens avec les parties prenantes islandaises concernées, issues de l'administration, de la politique, de l'industrie, de la science et de la société civile, ont permis de recueillir leurs points de vue sur les CCTS transfrontaliers avec stockage géologique en Islande.

En ce qui concerne les modèles organisationnels et financiers qui pourraient être envisagés pour une infrastructure de réseau de pipelines de CO_2 en Suisse, un aperçu complet des modèles potentiels à appliquer a été fourni. Dans l'ensemble, les modèles commerciaux réglementés avec une entité centrale d'exploitation semblent constituer l'approche de financement la plus appropriée pour un réseau suisse de gazoducs de CO_2, car ils combinent de faibles coûts de financement, des incitations à une exploitation efficace et la flexibilité nécessaire pour coévoluer avec l'émergence du réseau et avec les changements de l'environnement réglementaire au fil du temps.

Summary

Work package (WP) 5 of DemoUpCARMA assesses policy, regulatory, financial, and acceptance aspects of carbon capture, transport, and storage (CCTS) and carbon capture, utilization, and storage (CCUS) value chains and identifies potential gaps for their implementation and upscaling. To this end, this WP includes an analysis of climate finance instruments at domestic and international levels, an investigation of effective policy designs to overcome financing as well as potential public acceptance challenges, stakeholder analysis and suggestions for appropriate communication, and an assessment of technical and organizational issues regarding the scale-up of the required transport infrastructure.

Because of the novelty of the DemoUpCARMA pilot demonstrations as well as CCTS/CCUS value chains and their policy, regulatory, financial, and acceptance aspects overall, a range of qualitative and explorative methodologies were applied to approach the topics at hand; these included for instance a stocktaking and mapping of existing national and international best practices and workshops and interviews with relevant key stakeholders (such as national authorities, industry partners, subject matter experts, the public, associations, and companies from comparable industries, etc.).

While Switzerland has assigned CCTS/CCUS a prominent role in its long-term strategy to reach net zero GHG emissions by mid-century, the CCTS/CCUS value chains do not currently have a viable business case due to the associated high costs and insufficient returns on investment. To become economically viable, these technologies will likely require further economic incentives. To this end, an analysis of current and potential future climate finance instruments at the domestic and international levels both in Switzerland and other jurisdictions, and their potential for mobilizing and scaling CCTS/CCUS-based mitigation methods was performed. Several initiatives were identified in Switzerland and globally to support CCTS/CCUS activities in voluntary and compliance carbon markets, including carbon contracts for difference, tax incentives, or purchase agreements of various kinds. As a result of this landscape assessment, several opportunities were identified for stakeholders to act and contribute to addressing existing challenges and further scaling the deployment of CCTS/CCUS solutions.

As for the stakeholder mapping along the CCTS/CCUS value chains, stakeholders from science, business, politics, and civil society as well as the public were identified. Factors with a potential positive, negative, or ambivalent impact on the stakeholder perception of CCTS/CCUS were assessed. In addition, input from interviews with relevant stakeholders in Iceland from administration, politics, industry, science, and civil society on their perspectives on transboundary CCTS with geological storage in Iceland was collected.

As for organizational and financial models that could be considered for a CO_2 pipeline network infrastructure in Switzerland, an extensive overview of potential models to be applied was provided. Overall, regulated business models with a central operating entity seem to provide the most suitable funding approach for a Swiss CO_2 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.

Main findings

- Developing tailored strategic climate finance mechanisms, precise emission accounting tools and clear carbon market guidance is crucial for scaling CCTS/CCUS value chains. Sector-specific strategies, drawing on existing policies, are needed to address gaps and leverage national technology priorities. Establishing a robust carbon accounting framework applicable throughout these chains is key for quantifying carbon reductions, unlocking market revenue, and ensuring long-term credibility. Additionally, enhancing awareness of carbon market requirements among CCTS/CCUS industry actors is essential for improved access to carbon revenues.
- Implementing CCTS/CCUS within the Swiss ETS requires strategies to recognize emissions reductions, yet the existing price of allowances (even with adjustments) falls significantly short of the costs involved, hindering necessary investments. The integration of CCTS/CCUS into the ETS, coupled with free allocation, presents challenges regarding compliance with WTO subsidy rules. De-risking tools like Carbon Contracts for Differences (CCfD) could facilitate CCTS/CCUS adoption within ETS installations while adhering to WTO obligations. Proceeds coming from the auctioning of Swiss ETS allowances might not be sufficient to cover up existing needs for funding in the short- to mid-term but additional budgetary outlays should be considered as 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.
- Addressing CCTS/CCUS investment and financing requirements involves recognizing that CO_2 transport, particularly in capital-intensive assets like pipelines, is significantly impacted by financing decisions. In contrast, OPEX-intensive transport assets like trains are less influenced. Implementing policies like loan guarantees and investment subsidies could mitigate cost gaps between private and public financing, although factors like operational efficiencies or regional precedents may also sway preferences away from public financing.
- Stakeholder engagement for CCTS/CCUS in Switzerland involves a small group of experts from industry, public administration, research, and civil society, with a shared understanding and support for the concept, yet as implementation progresses, diverging interests and potential critical voices may emerge. Emitters and project developers emphasize the necessity of regulatory clarity, financing schemes, and comprehensive estimates of costs and CO_2 reduction efficiency throughout the project life cycle to ensure planning certainty. Engaging advocates, observers, cautious parties, and those unfamiliar with the topic requires a coordinated approach, addressing both systemic and local scopes of CCTS/CCUS projects with differentiation.
- The Swiss public's awareness of CCTS/CCUS pathways is generally low, with acceptance and support shaped by personal and social factors. Perception of benefits and risks varies based on specific pathways – domestic concrete CO_2 storage versus overseas underground storage – and trains are perceived as the most environmentally friendly transport mode. To effectively convey information, combining visual and written elements, particularly through infographics, is recommended as the preferred format for informational products.
- Addressing technical regulatory gaps for CO_2 pipelines in Switzerland requires federal-level constitutional amendments as the current authority rests with the cantons. Despite the absence of specific regulations for CO_2 transport, leveraging existing oil and gas pipeline regulations and general infrastructure standards offers a foundation. Additionally, reference to regulations from countries with disclosed plans for onshore CO_2 pipeline networks, such as Germany, and international standards like ISO, could inform the development of Switzerland's specific CO_2 pipeline regulations.

- Developing future CCTS infrastructure models in Switzerland involves managing significant risks and necessitates collaboration among numerous domestic and international stakeholders. Establishing a scaled-up CO_2 pipeline network demands low capital costs and concerted organizational efforts. Regulated business models featuring a central operating entity emerge as the most viable funding approach, blending low funding costs, operational efficiency incentives, and adaptability to network growth and evolving regulatory landscapes.

Contents

Abbreviations

BECCS	Bioenergy with carbon capture and storage
BMBF	German Federal Ministry for Education and Research
CBAM	Carbon border adjustment mechanism
CCFD	Carbon Contract for Difference
CCTS	Carbon capture, transport, and storage
CCU	Carbon capture and utilization
CCUS	Carbon capture, utilization, and storage
CDR	Carbon dioxide removal
CDR Swiss	Swiss Carbon Removal Platform
CO_2	Carbon dioxide
CRCF	Carbon Removal Certification Framework
DAC	Direct air capture
DACCS	Direct air carbon capture and storage
ETS	Emissions trading scheme
EU	European Union
FOEN	Federal Office for the Environment
KIG	Climate and Innovation Act
LCOT	Levelized Cost of Transport
SCM	Subsidies and Countervailing Measures
SFOE	Federal Office for Energy
GHG	Greenhouse gases
VCM	Voluntary carbon market
VCS	Verified Carbon Standard
VBSA	Swiss Association of Waste Treatment Plant Operators
WP	Work package
WTO	World Trade Organization

1 Introduction

1.1 Background information and current situation

Based on the pledges made in the frame of the Paris Agreement, Swiss emissions of greenhouse gases (GHG), particularly carbon dioxide (CO_2), will have to be substantially curbed in the next three decades. This objective was also anchored in the long-term climate strategy of Switzerland adopted by the Federal Council in January 2021, which states that GHG emissions must be reduced and eliminated as much as possible in each sector through technology and infrastructural changes or the promotion of alternatives. In 2050, GHG emissions are to be reduced to 90 percent compared to the 1990 levels. The remaining emissions, most notably an estimated 7 million tons of CO_2 per year (which includes 2 million tons of biogenic CO_2) from large point sources will need to be captured and stored using carbon capture, transport, and storage (CCTS) or carbon capture, utilization, and storage (CCUS) technology. In Switzerland, these large emitters are waste-to-energy plants, cement manufacturing facilities, and chemical plants. Moreover, negative CO_2 emissions, also in the order of millions of tons of CO_2 per year, will have to be generated to compensate for unavoidable residual emissions, predominantly in the agricultural sector, e.g., through the deployment of direct air carbon capture and storage (DACCS) and bioenergy with carbon capture and storage (BECCS). Scenarios including such pathways to a net-zero Switzerland are outlined in the long-term climate strategy of Switzerland, which quantifies the need for negative emission solutions beyond biogenic CCTS/CCUS at approximately 5 million tons of CO_2 per year in 2050.

To reach the Swiss climate goals, Switzerland's net-zero emissions pledges are to be translated into strong near-term policies and actions with a coordinated effort by key stakeholders. In this context, technology chains that will be part of the pathways outlined above must be demonstrated and their feasibility evaluated along technical, economic, environmental, political, and societal aspects. Furthermore, policies and regulations further supporting the scale-up of these pathways need to be explored. This is particularly important in the context of the newly adopted Climate and Innovation Act on 18 June 2023 and the revision of the CO_2 Act.

1.2 Purpose of the Work Package (WP)

DemoUpCARMA WP5 aims to address the challenges outlined above through the synergistic collaboration of a broad coalition of Swiss academic, industrial, and institutional partners, complemented by two pioneering European CO_2 storage hub initiatives. It assesses policy, regulatory, financial and acceptance aspects of CCTS/CCUS chains, and identifies potential gaps that must be overcome for the large-scale deployment of these technologies.

To this end, an analysis of promising climate finance instruments at the domestic and international level for the implementation and upscaling of CCTS/CCUS value chains, including but not limited to crediting mechanisms, is carried out. Following a stocktaking and mapping exercise to identify possible climate finance strategies based on the Swiss CO_2 law, international best practices, and other relevant policies, WP5 assesses in more detail the technical, regulatory, and financial feasibility of concrete climate finance options for the CCTS/CCUS activities. In addition, an analysis aimed at identifying potential strategies to allow emission reductions realized through carbon capture to be credited for compliance purposes to installations participating in the Swiss Emissions Trading Scheme (ETS) is conducted. The identification of viable options will pay due regard to the domestic obligations arising under the Swiss CO_2 Act for covered entities as well as relevant international obligations that could affect Switzerland's policy space such as international trade rules on subsidies and non-discrimination.

Furthermore, effective policy designs to overcome acceptance and financing challenges are investigated. Deploying CCTS/CCUS will require the mobilization of finance for the capital-intense technology chains as well as effective support policies to allow for investments into assets that are required along the CCTS/CCUS supply chain. For this, investment, and financing needs along the supply chain of CCTS/CCUS as well as effective support policy designs for mobilization of CCTS/CCUS and carbon capture and utilization (CCU) finance are examined as they constitute the two key economic/policy issues in the context of the DemoUpCARMA pilots and in view of a scaled-up CCTS/CCUS network. Support policies for CCTS/CCUS must be designed carefully, to ensure public acceptance of the CCTS/CCUS approach, and to mobilize necessary financial investments in a way that is efficient from a societal point of view. In this context, three policy issues associated with CCTS/CCUS are assessed in more detail by examining public and stakeholder support for/opposition to storing or utilizing emissions, public and stakeholder preferences over different policy designs, and how policy interventions to incentivize CCTS/CCUS deployment could affect public and stakeholder acceptance and thereby stickiness and ratcheting-up potential of support policies. In addition, the major stakeholders along the CCTS/CCUS value chains are mapped with the underlying goal of understanding their preferences and concerns, thus laying the groundwork for a potential future engagement activity beyond DemoUpCARMA.

Finally, this WP identifies regulatory gaps for the large-scale deployment of CCTS/CCUS and addresses technical and organizational issues regarding the scale-up of the required transport infrastructure. For this, regulatory challenges emerging from the two demonstration chains and the respective learnings and solutions thereof are collected and assessed through regular workshops with the relevant project partners. In addition, a first assessment of the pipeline-related technical regulatory landscape is provided, therefore laying the groundwork for the planning of the next steps to develop the identified regulatory aspects and solve the legislative challenges. Lastly, organizational, and financial models that could be considered for a CO_2 pipeline network infrastructure in Switzerland are outlined and analyzed.

1.3 Objectives

The first part of this WP aims to analyze effective policy designs to ensure public acceptance, mobilize financial investment, and guarantee the economic viability of CCTS/CCUS solutions. Policymakers are provided with a portfolio of pathways to incentivize the wide adoption of CCTS/CCUS technologies for the decarbonization of the Swiss economy in line with the findings of the Energy Perspectives 2050+ and towards Switzerland's net-zero target by 2050. In addition, effective and consistent monitoring, accounting, and allocation, and reporting tools for CO_2 emissions along CCTS/CCUS value chains are developed. Based on this, potential mechanisms to create and monetize emission reductions and removals generated through the utilization and storage of CO_2 domestically or abroad are provided. Also, blueprints for carbon credit and climate finance transactions to scale up the deployment of CCTS/CCUS solutions are developed.

Furthermore, this WP aims to understand CCTS/CCUS financing needs and how different support policies can overcome their financing challenges in Switzerland and beyond. An understanding of how public and stakeholder support for/opposition to storing or utilizing emissions is developed and complemented by an overview of how different support policies can influence public acceptance of CCTS/CCUS.

Lastly, WP5 identifies gaps and potential solutions concerning legal and regulatory frameworks relevant to CCTS/CCUS. Relevant bodies and experts are provided with a comparative assessment of regulatory pathways to enable and facilitate the development of CCTS/CCUS chains. Lastly, options for models organizational and financial models for pipeline network infrastructure and CCTS/CCUS plans in a Swiss context are investigated and assessed.

2 Procedures and methodology

2.1 Procedures and methodology of Task 1

2.1.1 Stocktaking, mapping, and strategy development (Subtask 1.1)

The team scoped the landscape of potential revenue sources such as carbon markets and national and international legislation. This has been done through an extensive literature review, engagement with industry and policy stakeholders, and an examination of the sector-specific challenges and opportunities associated with CCTS/CCUS.

2.1.2 Methodology development under the CCS+ Initiative (Subtask 1.2)

This subtask entailed the creation of two framework methodologies, accompanied by a variety of modules and tools designed for quantifying emissions reductions and removals for CCTS/CCUS activities. This integrated infrastructure simplifies carbon accounting for various technologically related project value chains by addressing capture, transport, utilization, and storage requirements individually. This modular approach empowers project proponents to customize their specific value chains, integrating their unique configurations for capture, transport, and storage. Additionally, it involved the development of supplementary guidance documents and tools for processes like distinguishing between emissions reductions and removals. Given its pioneering role as a methodological toolset, subtask 1.2 provides an up-to-date overview of carbon market expectations, offering industry partners and project developers the most current insights.

2.1.3 Blueprints for climate finance transactions (Subtask 1.3)

In anticipation of the complex playing field of carbon accounting, climate project development, and diverse monetization pathways, four documents – “blueprints” – have been developed, to guide prospective project developers and value-chain partners through the carbon project development process. These exemplify the requisite steps for specific CCTS/CCUS value chains – solutions offered by DemoUpCARMA stakeholders. The blueprints outline the key considerations and possibilities of revenue-generating carbon markets, such as certificate sales in the voluntary carbon market (VCM), the domestic compensation instrument within the domestic Swiss compliance market, international transfer of mitigation outcomes achieved abroad, and participation in ETSs.

The following value chains are covered:

1. CO_2 capture from a Swiss biogas upgrading plant, transport by truck, utilization, and storage in concrete in Switzerland.
2. Collaboration between solid waste incinerators in Switzerland capturing CO_2, transport by truck, train, barge, and ship, and storage in saline aquifers in Norway.
3. CO_2 capture from cement plants, transport by truck, train, barge, and ship, and storage in Iceland via subsurface mineralization in igneous rock formations.
4. CO_2 capture from a biogas upgrading plant abroad, transport by truck, utilization, and storage in concrete abroad.

The blueprints are also differentiated by geographical focus (inland-only, transport for storage abroad, abroad-only), which holds implications on the applicability and steps needed to pursue revenue-generating market instruments.

2.1.4 Potential strategies to acknowledge emissions reductions achieved through CCTS/CCUS by emitters participating in the Swiss ETS (Subtask 1.4)

With a view to identify and explore options suitable to make the Swiss ETS instrumental to trigger investment in CCTS/CCUS technologies, this subtask involved an analysis of the Swiss legal landscape governing the ETS in general and the integration of CCTS/CCUS in particular against the backdrop of the European Union (EU) experience. This led to a stocktaking of existing gaps, challenges and opportunities arising from 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 CO_2 Act and Ordinance, on the other hand. Based on a comparative analysis, extensive literature research, and engagement with industry and policy stakeholders, the subtask worked on the definition of a combination of instruments that could altogether contribute to encouraging the uptake of CCTS/CCUS technologies among ETS installations. It prioritized those options that could be built-in within the Swiss ETS and explored pros and cons of each option in light of their legal implications (including from an international perspective, i.e., based on World Trade Organization (WTO) rules).

2.2 Procedures and methodology of Task 2

2.2.1 CCTS/CCUS investment and financing needs (Subtasks 2.1-2.2)

The work focuses on identifying suitable financing structures for different CO_2 transport methods and evaluating how these choices affect the costs of long-distance, large-scale CO_2 transport in Europe.

Simultaneously, we built a techno-economic model that incorporates these financing structures and blends them with the technical costs of each transport mode. This model calculates the Levelized Cost of Transport (LCOT), examining the effect of the financing structures on it under various scenarios, including transport distance and capacity. Inputs for LCOT were drawn from existing academic literature (see literature list in results) and from work by Pauline Oeuvray in DemoUpCARMA WP4.

To validate our data, we interviewed six experts in CO_2 transport and financing, with more interviews scheduled for late 2023. Initial findings from our study were shared at the DemoUpCARMA consortium meetings as well as at the DeCIRRA "CO_2 Pipeline Workshop" at ETH Zurich (December 2022). We engaged with diverse stakeholders, including policymakers and industry experts, to discuss our preliminary observations. The collected feedback was integrated into our research.

2.2.2 Public acceptance of support policies (Subtask 2.3-2.5)

To assess public acceptance of CCTS/CCUS policies, we rely on a public opinion survey and survey-embedded choice experiments, which we conducted in Switzerland. For the survey fielded in spring 2023, we sampled 1,500 respondents per choice experiment based on nationally representative characteristics (i.e., gender, age, and education). We did this in cooperation with the company Bilendi who provided us access to their Swiss panels. The experimental setup is outlined as described in Figure 1 below:

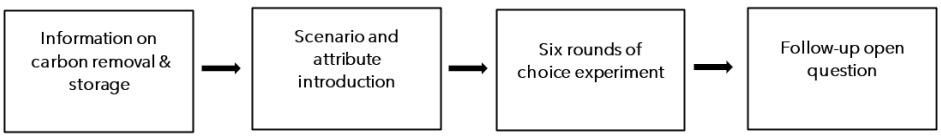

Figure 1: Visualization of study design.

Choice experiments allow researchers to systematically study how citizens form policy preferences in complex, multidimensional situations. They expose respondents to potential policy scenarios that consist of several randomly varying design features manipulated by the researchers. Our respondents were exposed to five unique choice rounds in which they were asked to evaluate two policy scenarios displayed next to each other. After each round respondents can decide which policy proposal they prefer (equal to a forced choice) and whether they support or oppose the two individual policy proposals. To account for unreliable respondents, we included a sixth choice round in our experiment that showed respondents the reversed version of the first profile they received (Version 1: Proposal A, B; Version 2: Proposal B, A). If respondents did not choose the same profile twice, we flagged them as unreliable. This enables us to account for potential measurement errors.

In addition to the experimental survey part, we also collected qualitative data based on open-ended questions. This enables us to improve our understanding of the motivation behind respondents' preferences. After respondents completed the choice experiment, they needed to rank all attributes of our policy proposals from most to least important. Based on this ranking exercise we asked them why the chosen attribute is the most important to them. We performed a systematic qualitative text analysis of the 1,500 open-ended answers we received per choice experiment.

2.2.3 Stakeholder engagement for CCTS/CCUS in Switzerland (Subtask 2.6)

As a basis for the CCTS/CCUS stakeholder mapping and recommendations for stakeholder engagement, we conducted 17 semi-structured interviews with Swiss stakeholders. The interviewees were experts and practitioners from industry, research, civil society, administration, and politics. Most of the interviewees were familiar with and/or actively engaged with the topic. The interviews were complemented with desk research, a joint questionnaire answered by 12 members of the DemoUpCARMA consortium and the federal offices FOEN and SFOE, as well as informal exchanges and workshops with stakeholders in Switzerland and other European countries.

The insights from the interviews and exchanges were used to map relevant stakeholders to key stakeholder groups and to assess their interests, scopes of influence, levels of engagement, and premises regarding CCTS/CCUS. For the mapping, we followed a top-down analytical approach, defining stakeholder groups based on their interests and scopes of influence regarding CCTS/CCUS. We derived recommendations, based on the assessment of stakeholder positions and premises, combined with insights from literature and the practical experiences of Stiftung Risiko-Dialog. With a focus on generating applicable results and recommendations, we combined a descriptive approach with normative and instrumental perspectives, asking who should be engaged and what is required from whose perspective to develop a position and make decisions regarding the implementation and potential upscaling of CCTS/CCUS in Switzerland.

More details and the questions from the semi-structured interviews and questionnaire are provided with Appendix E - Subtask 2.6 - *Stakeholder Engagement for CCTS and CCUS in Switzerland.*

2.2.4 Current knowledge and public perception of the Swiss public towards CCTS/CCUS (Subtask 2.7)

We applied a transdisciplinary approach, by collaborating with scientists from different disciplines and involving the general public. This allowed us to consider the latest research findings gained in the project DemoUpCARMA, address the research questions from different scientific perspectives, and consider public perspectives.

Thus, we designed the communication products in collaboration with CCTS/CCUS experts, communication specialists, and graphic designers to test them with the general public. For the testing,

we first conducted in-person focus groups and then an online survey (see Figure 2), enabling us to understand people's thinking in-depth and to generalize our findings to the Swiss population. 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 focus groups were recruited via sports, culture, and religious associations, and the online survey participants through the ISO-accredited polling company Bilendi. Both studies were approved by the Ethics Committee of ETH Zurich (EK 2022-N-105).

The detailed focus group procedure and the questionnaires in German and French are provided in Appendix F – *Deliverable 5.6 – Report on the current knowledge and public perception of the Swiss public towards CCTS and CCUS.*

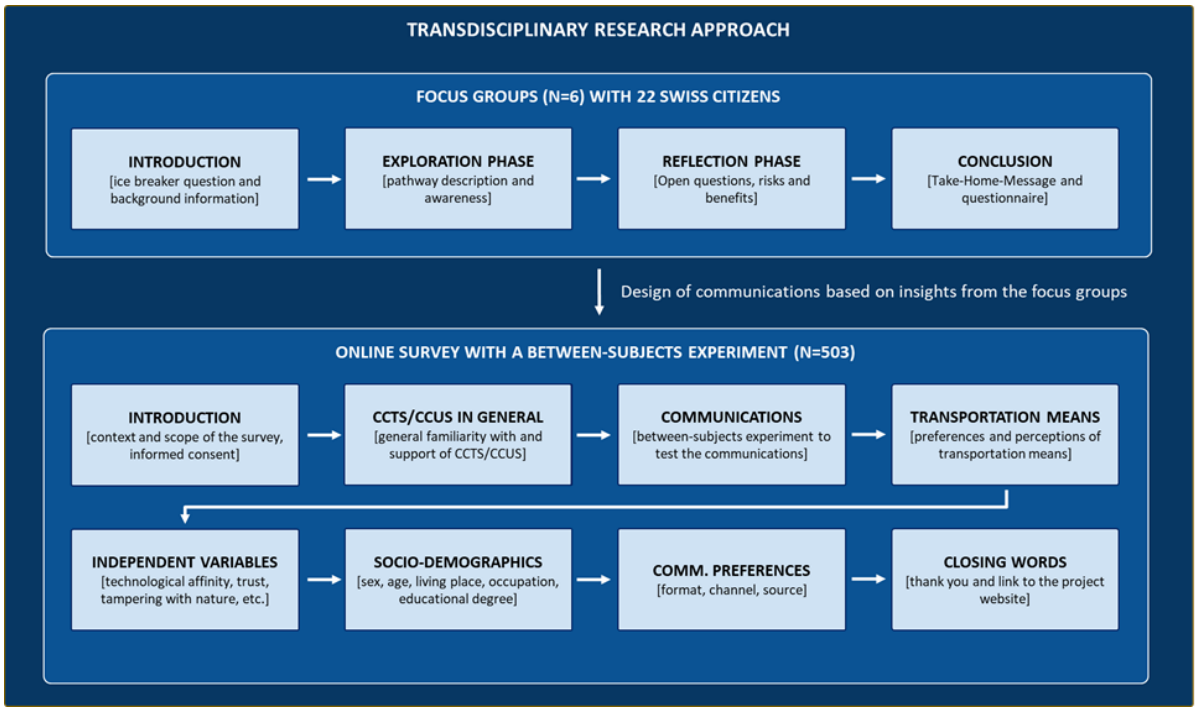

Figure 2 Overview of the studies conducted in subtask 2.7. The detailed focus group procedure and the questionnaires in German and French are available in Appendix F.

2.3 Procedures and methodology of Task 3

2.3.1 Technical regulatory gaps for CO_2 pipelines (Subtask 3.1)

The scope of the assessment of technical regulatory gaps for CO_2 pipelines was defined as follows: the term 'technical' refers to the mechanical and environmental aspects of design, construction, and operation of a CO_2 pipeline rather than financial and organizational aspects (which are addressed in DemoUpCARMA WP5, Subtask 3.2 – *Organizational and financial models for future CCTS infrastructure*). The term 'regulatory aspects' encompasses laws and regulations as well as national and international standards. Lastly, the focus is on CO_2 pipelines in Switzerland rather than CO_2 capture units or storage sites.

As a starting point for the assessment, general competencies for the development of legislation and technical regulations for CO_2 pipelines are investigated due to their importance in providing a certain framework and boundary conditions for more detailed development of laws and regulations.

Second, key technical regulatory aspects and assumptions that emerged from a first conceptual study for a CO_2 pipeline collection network in Switzerland (conducted by the Italian pipeline engineering company Saipem and led by the Swiss Association of Waste Treatment Plant Operators (VBSA)) and from consultations with relevant stakeholders are identified and described. 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 have to be considered for the design, construction, or operation of larger infrastructure projects, are analyzed.

Third, existing international standards as well as current and developing technical regulatory frameworks for CO_2 pipelines in selected countries are investigated. These countries have been identified as the most relevant cases for consideration due to the state of progress of their CO_2 pipeline projects and the availability of accessible information at the time of conducting this research.

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 existing technical regulations for CO_2 pipelines, the work and outcome of this subtask are mainly geared at providing a first overview of technical regulatory aspects to focus on for CO_2 pipeline networks in Switzerland and serve as a starting point for further in-depth analysis to provide conclusive recommendations.

2.3.2 Organizational and financial models for future CCTS infrastructure (Subtask 3.2)

The starting point for the assessment of organizational and financial models for future CCTS infrastructure is the conceptual study (conducted by Saipem and led by VBSA) on the feasibility and costs of a CO_2 pipeline network in Switzerland. Building on these findings, the investment in a Swiss CO_2 pipeline network is characterized and defined in terms of investment needs, potential funders and ownership, coordination and regulation requirements, revenue model, risk management, and cost of capital. Each of these elements is described in the specific considerations made for investments in a Swiss CO_2 transport network.

As the next step, models of how such an investment could be organized and financed are examined in three different sets of comparable precedent cases. At first, the organizational and financial models that are used or proposed for CO_2 pipelines in Europe are analyzed. The history of funding CO_2 pipelines in Europe is briefly described and current plans for large-scale CO_2 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.

Secondly, given the very limited amount of practical experience found in funding CO_2 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 CO_2 pipeline network. Regulatory business models are identified as the most interesting funding and governance mechanism based on the characteristics defined previously. Further, the organizational and financial models used for gas pipelines, electricity grid, water transmission networks and highways in Switzerland are analyzed.

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. The 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 CO_2 pipeline networks in Switzerland and serves as a starting point for further in-depth analysis to provide conclusive recommendations.

3 Results and discussion

3.1 Results and discussion of Task 1

3.1.1 Stocktaking, mapping, and strategy development (Subtasks 1.1)

Policy pathways are not always straightforward and can contain unpredictable surprises. An example of this was the 2021 public vote against extending and adopting the revised CO_2 act, which would have provided the foundation for extending and building on provisions aimed at incentivizing CCTS/CCUS-related activities. However, this development was followed by the adoption of the Climate and Innovation Act (KIG) – offering a longer-term perspective and opportunities for further-reaching measures in Swiss climate policy. Similar examples of such dynamics and uncertainties can also be found in the European context wherein the Carbon Removal Certification Framework (CRCF) represents an ongoing process toward certifying removal results – including from CCTS/CCUS – with an uncertain role toward carbon markets and regulation. Subtask 1.1 sought to navigate regulatory uncertainty and identify overarching and specific opportunities for action by both public and private actors in the medium term. The aim is to strengthen the scalable business case of CCTS/CCUS through credible and viable long-term carbon revenue.

The stocktaking identified strategies that may encourage the advancement and adoption of CCTS/CCUS technologies, while also pointing to a need for foundational policy decisions regarding for example the scope of the ETS and the envisaged role of regulatory approaches (e.g., sector agreements) in the longer term. This is because the challenges evolve from piloting phases to subsequent scaling. Technology value chains also see different challenges resulting from e.g., the size of point sources and the varying economies of scale and transport cost respectively. Strategies chosen for each specific value chain may thus have to be customized and flexible to respond to evolutions in regulation and market conditions that may offer opportunities for mobilizing the premium prices required for CCTS/CCUS.

The main insights (major gaps, challenges, and opportunities of the stocktaking and strategy development phase revolve around the need to ensure that investments in Carbon Capture, Utilization, and Storage become bankable with high revenue certainty that matches the investment scale and cost for private sector entities. Key considerations include:

- Long-Term Policy Stability: The experience with enduring carbon taxes in Nordic countries and feed-in tariffs globally highlights the importance of stable, long-term public policies. These policies create the necessary certainty over carbon revenues, which is essential for pursuing CCTS/CCUS on a large scale and in a cost-effective manner. It's crucial to balance the cost implications of these policies for taxpayers and consumers while ensuring their stability, as seen in Germany's feed-in tariffs.
- Overcoming the Valley-of-Death: For CCTS/CCUS projects heavily reliant on carbon revenues, maintaining the credibility of future carbon revenues is critical. Fluctuations in carbon market prices or eligibility uncertainties can jeopardize financial feasibility. Policies need to support these technologies in overcoming initial financial hurdles and reaching commercialization stages.
- CO_2 Storage Supply and Demand Mismatch: As European countries aim for net-zero emissions, the demand for durable CO_2 storage is expected to rise significantly. However, there's a potential mismatch between the scaling of CO_2 capture projects and the development of

transportation and storage infrastructure. Policy instruments should address potential bottlenecks and ensure parallel development of capture projects and necessary infrastructure.

- Persistent Investment Risks: Despite robust demand-pull instruments, the investment risks for CCTS/CCUS projects may still deter private investors. Measures to mitigate these risks, such as market price stabilization or establishing price floors, could be vital in making these investments more attractive to the private sector.
- Inefficiencies and Windfall Profits for Storage Providers: The potential market concentration among storage providers poses risks of inefficiencies and excessive costs for CCTS/CCUS projects. Regulatory interventions may be needed to address the imbalance of information on costs between storage providers, project partners, and policymakers, especially when financial flows are government-administered.

Overall, the emphasis is on creating a business environment where revenue certainty from CCTS/CCUS investments is high enough to make them the safest and most attractive option for private sector investors. This involves ensuring policy stability, effectively managing the supply-demand dynamics for CO_2 storage, reducing investment risks, and addressing potential market inefficiencies.

For detailed insights into the stocktaking, mapping, and strategy development, please refer to:

- Appendix A1 - Subtask 1.1 - Inception report
- Appendix A2 - Subtask 1.1 - Briefing note - Climate finance landscape assessment.
- Appendix A3 - Subtask 1.1 - Stakeholder engagement.
- Appendix A4 - Subtask 1.1 - Strategy paper - Enabling CCTS and CCUS value chains for Swiss climate neutrality.

The inception report (Appendix A1) offered an overview of the approach to subtask 1.1, 1.2, and 1.3 and offered a summary of first findings of preliminary work as well as a description of subsequent steps. The briefing note (Appendix A2) lays out the key challenges and opportunities toward mobilizing CCTS/CCUS through various possible steps by government as well as private sector entities. The stakeholder engagement report (Appendix A3) outlines the key interactions undertaken under this project to gather information on stakeholders' levels of understanding, perceived support needs and experienced challenges. The Strategy paper (Appendix A4) gave a forward-looking examination specified to the sectors involved in the DemoUpCARMA value-chains on specific steps toward financially mobilizing these climate change mitigation efforts.

3.1.2 Methodology development under the CCS+ Initiative (Subtask 1.2)

The development of a comprehensive carbon accounting infrastructure under Verra's Verified Carbon Standard (VCS) Program, led by the multi-stakeholder CCS+ Initiative, has made substantial progress over the past months. Since its foundation in mid-2021, the initiative has started to shape and co-develop an entire suite of VCS methodologies for generating carbon credits for various project types of CCTS/CCUS value chains.

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 covering a diverse range of CCTS/CCUS activities. Those methodological approaches currently available for CCTS/CCUS are limited in numerous ways, e.g., lacking clear and consistent definitions of project eligibility and project boundary,

having weak guidance on the implementation of additionality testing, or being 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. Its entire infrastructure is designed in an innovative plug-and-play modular fashion. Individual activities in the CCTS/CCUS value chain, are represented by respective methodological modules, separated in the capture, transport storage or long-term utilization, which can be seamlessly combined with the relevant modules of other activities. A more detailed introduction to the CCS+ methodological work can be found in Appendix B.

The methodological development has taken longer than initially foreseen in the DemoUpCARMA proposal and interim report because it adopted a more inclusive robust process and expanded the scope of the methodologies. First, the Initiative has grown to a multi-stakeholder initiative with more than 50 members, each contributing and bringing in their specific use cases to the ever-evolving methodologies. Second, the scope initially foreseen has been expanded in numerous ways, with entirely new methodologies, methodological modules, and tools as well as guidance notes being added to the work plan. The Initiative has, together with its members, collectively decided to prioritize quality and environmental integrity over speed. Co-developing the methodologies in close collaboration with its 50+ members guarantees that the methodologies are fit for purpose and can be adopted quickly once approved.

Thanks to its thorough, inclusive process, the Initiative's work has been met with keen interest by public policy shapers. It has facilitated an ongoing exchange between the Initiative's Secretariat and its technical experts and Commission members of the EU, (developing the EU CRCF the United States Department of Energy (US DoE; piloting CCTS/CCUS-based carbon credit purchases) as well as the UN's Paris Agreement Article 6.4 Supervisory Body (developing the rulebook for the UN carbon market MRV system). This exchange has been serving both to inform these policy actors on the challenges encountered and possible resolutions as well as to ensure that VCM methodologies are aligned with regulators' expectations such that VCM projects may also serve to gather relevant lessons that may be applied also in the future under compliance carbon markets – dedicated guidance documents lay out what the steps may be for transferring and recognizing efforts undertaken in context of VCM projects under compliance systems.

The methodological documents to be delivered under this WP will be made publicly available in due time. They are already being used by CCS+ members to start the development of their carbon credit projects. Some methodology modules have already been made public for external scrutiny. Once officially released by Verra, the CCS+ Initiative methodologies and their subsequent modules will become a valuable public resource, available for use by any CCTS/CCUS project developer, as well as all DemoUpCARMA project stakeholders. In conjunction with the Blueprints (Subtask 1.3), these resources will collectively establish a distinctive foundation for CCTS/CCUS stakeholders entering the realm of project development under the VCM. They also serve as a reference for those seeking a deeper understanding of carbon accounting in this field.

Table 1 below includes a comprehensive list of CCS+ Initiative carbon accounting infrastructure documents, along with their current development status. Methodologies address broad issues related to carbon accounting throughout CCTS/CCUS value chains, encompassing aspects such as emission reduction calculations and procedures that cover the entirety of project activities, including CO_2 capture, transport, and storage. The subsequent modules are categorized into CO_2 capture, CO_2 transport, and CO_2 storage activities, delving into topics such as monitoring parameters and project emissions specific to particular technologies. Additional tools (e.g., to differentiate emissions reductions and removals, see table 1) come into play for certain project types, for example in cases where it is essential to differentiate between biogenic and fossil CO_2 emissions within a single CO_2 stream. Table 2 provides a summary of

all guidance notes, which explore the application of the carbon accounting infrastructure for industrial carbon management.

Table 1: Overview of methodological outputs.

Methodological document	Project scope	Status
Methodology for Carbon Capture and Storage (CCS)	Yes	Public consultation completed
Methodology for Carbon Capture, Utilization, and Storage (CCUS)	No	Concept Note
Methodology for short-term utilization of Carbon (CCU)	No	Under discussion
Methodology for Carbon Dioxide Removal (CDR)	No	Under discussion
CO_2 Capture from Air (DAC)	No	Public consultation completed
CO_2 Capture from Biogenic Sources (BECCS)	Yes	Pre-public consultation, PC expected for Q4/2023
CO_2 Capture from Power and Heat	No	Pre-public consultation, PC expected for H1/2024
CO_2 Capture from Industrial Processes	No	Pre-public consultation, PC expected for H1/2024
CO_2 Capture from Oil and Gas	No	Pre-public consultation, PC expected for H1/2024
CO_2 Capture from Pre-combustion/Oxyfuel	No	Pre-public consultation, PC expected for H1/2024
Consolidated Module for CO_2 Transport via Pipeline, Ships, Trucks and Rail	Yes	Public consultation completed
CO_2 Storage in Saline Aquifers	Yes	Public consultation completed
CO_2 Storage in Depleted Oil and Gas Reservoirs	Yes	Pre-public consultation, PC

		expected for Q4/2023
CO_2 Mineralization in igneous rock formations	Yes	Concept Note
Utilization of CO_2 in concrete	No	Concept Note
Utilization of CO_2 in aggregates	No	Concept Note
Utilization of CO_2 in short lifetime products (fuels)	No	Under discussion
Utilization of CO_2 in short lifetime products (plastics)	No	Under discussion
Tool for Differentiation between Emission Reductions and Removals in Carbon Capture and Storage Projects	Yes	Pre-public consultation, PC expected for Q4/2023
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	No	Pre-public consultation, PC expected for Q4/2023

It is important to note that for the final approval, the regular VCS process requires any methodology developer to submit their drafted methodologies for public consultation. During this period, stakeholders and experts can provide feedback. The methodology developer is required to address all comments received and revise the methodology accordingly. The revised version is then further checked by an independent third-party organization, the so-called validation and verification body. Only if this independent check is completed, the methodologies can be approved by Verra, which then allows their use by project developers. Once the documents are ready for public consultation or are published by Verra, the link to the methodologies on the VCS website as well as any public consultation announcements are published on the CCS+ Initiative website[1].

The methodological documents included in Table 1 above and marked “Public consultation completed” were submitted already for public consultation in July 2023. Hence, they are publicly available on Verra’s website. The methodological documents included in Table 1 above and marked “pre-public consultation” are currently being prepared for public consultation in Q4/2023 and H1/2024 respectively, hence are not publicly available and cannot be published yet. The methodological documents included in Table 1 above and marked “Concept Note” are from an earlier conceptual stage and are not publicly available, hence cannot be published yet. The methodological documents included in Table 1 above and marked “Under discussion” will be developed if CCS+ members approve their scope. The same process applies to the status of the guidance notes included in Table 2 below. The EU guidance note is publicly available on the CCS+ website, the soon-to-be finalized Article 6 note will also be published there.

It has become evident that mobilizing potential synergies between policy contexts and opening possible avenue toward scaled revenue opportunities, which is why the team has also engaged in developing guidance notes, which outline steps toward possible transformation of projects initially conceived for the VCM to become eligible under policy instruments and systems such as the EU ETS, Article 6 transactions as well as various examples of national policy (table 2).

[1] http://ccsplus.org/

Table 2: Overview of guidance notes

Guidance Note	Project scope	Status
EU Guidance Note	No	Published
Article 6 Guidance Note	No	To be published in Q4/2023
US Guidance Note	No	In progress
Three domestic use cases: Switzerland & Sweden & Kenya	No	Under discussion
Using CCS+ outputs to create a race-to-the-top across all carbon crediting programs in the VCM	No	Under discussion
Gulf Region Guidance Note	No	Under discussion
Cross-border use cases: Norway-Denmark & Japan-SEA & Switzerland-Iceland	No	Under discussion

3.1.3 Blueprints for climate finance transactions (Subtask 1.3)

A series of four blueprints has been crafted to empower project developers in Switzerland, guiding them toward the monetization and expansion of CCTS/CCUS initiatives across diverse market scenarios, encompassing voluntary and compliance markets, both at the domestic and international levels.

These blueprints all delve into the following market contexts:

- VCM: the dynamics of certificate sales within the VCM.
- Swiss Compliance Market: domestic compensation instrument in Switzerland.
- Article 6.2, and Article 6.4: international transfer of mitigation outcomes achieved abroad.
- ETSs: trading systems empowering CCTS/CCUS projects.

Each blueprint aligns its focus with a specific CCTS/CCUS value chain, detailed in Section 2, "Procedures and Methodology." These blueprints serve as companions for CCTS/CCUS partners and prospective project developers, providing them with a first straightforward explanation of whether and how they may pursue revenue generation via the carbon market options presented.

Project developers and their value chain partners are initiated into the standards of the VCM and guided on how to meet compliance requirements. This includes clarifying technical considerations for developing the Project Design Document and covering elements such as the activity outline, baseline, and monitoring methodology. These technical requirements are essential not only to ensure compliance with the standards, but also to achieve the purpose of standards, namely, to maintain transparency, high quality, and environmental integrity for the emission reduction and removal credits produced.

In addition to explaining the process for VCMs, the blueprints further navigate the Swiss compliance market, which also involves certificate issuance and revenue generation from their sale. Key distinctions between the two markets are analyzed, allowing the reader to understand the eligibility of their planned CCTS/CCUS value chain and the respective steps involved.

In addition, the blueprints explain interlinkages with international compliance markets including the ETS, and transactions under the Paris Agreement (Article 6.2 and Article 6.4). Interlinkages are explained in such a manner as to equip project developers with the key insights needed to understand the differences and the prospects of unlocking premium prices in one or the other system.

Further detailed information can be found in the attached blueprints:

- Appendix C1 - Subtask 1.3 - Blueprint 1 - Domestic CCUS value chain - Biogas upgrading capture with storage in concrete in Switzerland.
- Appendix C2 - Subtask 1.3 - Blueprint 2a - International CCUS collaboration - Swiss solid waste CO2-capture for storage.
- Appendix C3 - Subtask 1.3 - Blueprint 2b - International CCS collaboration – Swiss CO2 capture on a cement plant and storage in Iceland.
- Appendix C4 - Subtask 1.3 - Blueprint 3 - Abroad CCUS value chain – Biogas upgrading capture with utilization in concrete.

3.1.4 Potential strategies to acknowledge emissions reductions achieved through CCTS/CCUS by emitters participating in the Swiss ETS (Subtask 1.4)

Scaling up investment in CCTS/CCUS technologies will require (re-)designing support policies for the purposes of generating revenue streams for Swiss firms engaging in CCTS/CCUS activities. This sub-task aimed at assessing whether and, if so, how the Swiss ETS could be revamped with a view to integrate CCTS/CCUS activities in a way that would contribute triggering investment on the part of ETS installations, while still in keeping with existing international commitments.

The one option that is concretely envisaged in the newly revised CO_2 Act starting from 2025 is exempting ETS installations from the obligation to surrender emission allowances for the portion of CO_2 coming from fossil origin and from process emissions that is durably stored in EEA countries in accordance with the EU CCS Directive (essentially replicating the exemption regime that is already in place within the EU ETS). Owing to the considerably higher costs incumbent on Swiss installations investing in CCTS/CCUS per ton of CO_2 as compared to the current price of emission allowances, however, this is a necessary but not yet sufficient step forward. For the exemption regime to yield the desired results, the Swiss ETS will need to be strengthened to produce a stronger carbon price signal – and hence higher revenue streams coming out of the exemption.

The combination of CCTS/CCUS integration with free allocation may further decrease the costs borne by Swiss ETS installations engaged in CCTS/CCUS activities, especially if acknowledging CCTS/CCUS-induced emission reductions bring ‘actual’ emissions close to (and eventually below) the benchmark for free allocation. At the same time, free allocation remains extremely problematic from a trade law perspective as it might constitute a prohibited or actionable subsidy within the meaning of the WTO Agreement on Subsidies and Countervailing Measures (SCM). Accordingly, the phasing down of free allocation, as it is already envisaged in the latest EU ETS revision, is needed to expose ETS installations to the full costs of their non-captured carbon emissions. Aligning with the EU trajectory is also required under the Linking Agreement on the ETS of the EU and Switzerland.

While the EU plans to substitute free allocation with the Carbon Border Adjustment Mechanism (CBAM), the Federal Council seems to have excluded this option for now. This type of instrument, albeit very complex and ambiguous as to its WTO compatibility, could be designed in a way to further contribute to incentivizing CCTS/CCUS among ETS installations (e.g., by taking CCTS/CCUS into account in methodologies for calculating embedded emissions and envisaging adjustments on the export side).

Given the 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 (even when corrected by free allocation) and CCTS/CCUS costs. De-risking instruments such as carbon contracts for difference (CCfD) – that is, 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 a 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) – could provide for an additional support measure through which the government could contribute to the added costs of CCTS/CCUS without excessive spending. This would be important to the extent that the Swiss ETS revenues are not comparable to the EU ETS revenues flowing into the Innovation Fund. This means that proceeds coming from the auctioning of Swiss ETS allowances might need to be complemented with additional budgetary outlays in the short- to mid-term (e.g., in the case Switzerland implements it, another potential source of funding could also be CBAM revenues). Existing studies, however, show that 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 carbon rises (Richstein, 2017; Ismer et al, 2023). Importantly, CCfDs could be designed in a way that ensure their compatibility with the SCM Agreement to the extent the level of support could be set by the market through a competitive discovery process such as auctioning. The reference price could be the ETS allowances price, but again intricacies would arise when it comes to deciding how to account for free allowances. Further details are provided in Appendix D – *Subtask 1.4 – Making the Swiss Emission Trading Scheme Work for CCS: A Legal Analysis*.

3.2 Results and discussion of Task 2

3.2.1 CCTS/CCUS investment and financing needs (Subtasks 2.1-2.2)

Deploying CCTS/CCUS will require the mobilization of finance for the capital-intense technologies and requires effective support policies to allow for investments into assets that are required along the supply chain.

The objective of subtasks 2.1 and 2.2 is to understand the investment and financing needs for CO_2 transport infrastructure in Europe. While related work, such as the meta-study published in Nature Climate Change by the Climate Finance and Policy Group (Klaaßen & Steffen, 2023), offers a comprehensive perspective on investment needs in CCTS/CCUS, our focus is specifically on the transport segment of the CO_2 supply chain. We identified this as the most substantial research gap in terms of costs and financing needs.

To accomplish this, we begin by calculating the costs associated with various modes of CO_2 transport, including pipelines, ships, barges, and trains. Following the cost assessment, we identify potential financing structures, encompassing both public and private sources, to evaluate how investments in the transport modes could be feasibly supported. A series of expert interviews is conducted to ensure the validity of the assumptions. Finally, we examine how different financing structures impact the cost of capital and, by extension, the overall cost of CO_2 transport.

Preliminary cost of capital results

Cost of capital calculations were made for CO_2 transport through four different financing structures. Public financing consistently showed the lowest cost due to its dependence on low-interest public debt, whereas the highest cost arose from unregulated corporate finance, influenced by more costly private debt. Costs also significantly differed based on the levered beta, which mirrors the asset risk specific to each transport asset. In addition, our cost of capital estimates in the study were found to be more optimistic than in previous studies, so we include an analysis of interest rate scenarios to account for

the impact of different interest rates on the cost of CO_2 transportation. It is important to understand the impact of interest rates on transport costs, as interest rates have risen sharply in recent months.

Cost of CO_2 transport across transport assets
CO_2 transport costs are determined by the volume of CO_2 transported and the distance covered. As distance grows, costs rise for all transportation methods. For onshore routes, pipelines appear to be most efficient, especially for large CO_2 quantities. On the other hand, for offshore routes, low-pressure dedicated ship transport emerges as the most economical, but offshore pipelines could be viable for large CO_2 volumes, given certain conditions.

Impact of financing structures on the cost of CO_2 transport
The cost of CO_2 transport for a set distance and mass flow was analyzed across multiple transport assets and financing structures. The least expensive was again found to be public finance due to low-interest public loans. Costs for pipelines, both onshore and offshore, varied greatly with the financing structure, primarily since pipelines are capital-intensive assets. For trains, the financing's impact on costs was limited. This distinction is crucial, as the choice of financing significantly affects the cost structure, especially for pipelines which can account for up to more than 50% of total costs.

Ex-ante policy scenarios for onshore pipeline
The influence of financing structures on the levelized transport cost of onshore pipelines is significant. Leveraging expert insights and existing literature, two policy scenarios were introduced: loan guarantees and investment subsidies. Loan guarantees, backed typically by the government, can reduce market risk premiums in equity costs, but they do not achieve the same low costs as public finance. On the other hand, investment subsidies directly reducing initial capital requirements can bring private financing costs closer to public finance costs. Yet, even with these interventions, public finance consistently emerges as the most cost-effective, raising questions about optimal resource allocation in future policies.

3.2.2 Public acceptance of support policies (Subtask 2.3 - 2.5)

To define our objective, we first conducted a literature review to uncover potential public acceptance challenges related to policy designs incentivizing CCTS/CCUS and CDR including biogenic CCTS/CCUS. So far literature assessing public acceptance usually applies a socio-technological perspective that focuses on public perception of distinctive technological features with an emphasis on the geological storage of CO_2. The core findings of this literature review are (see L'Orange et al. 2014; Tcvetkov et al. 2019 for a systematic overview of studies):

- Knowledge and awareness on CCTS/CCUS and CDR including biogenic CCTS/CCUS technology are very limited among the public in a variety of countries among them Switzerland; as deployment of technologies progresses public awareness increases (e.g., Norway and Netherlands usually report the highest familiarity).
- Public perception of CCTS/CCUS and CDR including biogenic CCTS/CCUS technology is neither strongly positive nor negative. This makes public opinion susceptible to information provision (e.g., risk information) and specific project characteristics (e.g., involvement of fossil fuel companies). CCTS/CCUS and CDR including biogenic CCTS/CCUS technology is viewed more favorably compared to nuclear waste or geoengineering approaches like solar radiation management but less favorably than renewable energy projects.

Acceptance of CCTS/CCUS and CDR including biogenic CCTS/CCUS projects depends on:

- the specific technology used (e.g., CCTS/CCUS with bioenergy viewed more favorably compared to CCTS/CCUS with coal-fired plants, and afforestation/reforestation are perceived

more favorably compared to CDR including biogenic CCTS/CCUS technology) (Duetschke et al. 2014; Dütschke et al. 2016; Jobin and Siegrist 2020; Wenger, et al. 2021)

- perceived risks and benefits of the technology (Cox, Spence, and Pidgeon 2020; Kraeusel and Möst 2012)
- trust in the actors involved in projects (e.g., trust reduces risk perceptions) (e.g., Huijts et al.; Offermann-van Heek et al. 2018)
- early involvement of communities 1) in the decision-making process surrounding the project and 2) by providing information beyond the social desirability of the project like costs and benefits for the community (e.g., Brunsting et al. 2011; Dütschke 2011)
- proximity of (potential) CO_2 storage sites to one's residence (Not-In-My-Backyard concerns) (e.g., Braun 2017; Krause et al. 2014)

Public perception of policies that incentivize CCTS/CCUS and CDR including biogenic CCTS/CCUS technology is so far understudied (Bellamy, Lezaun, and Palmer 2019).

3.2.3 Stakeholder engagement for CCTS/CCUS in Switzerland (Subtask 2.6)

The realization of CCTS/CCUS 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. The engagement with stakeholders around the implementation of CCTS/CCUS is necessary for both normative and instrumental reasons. The goal of this subtask was to lay the basis to facilitate 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?

Key results per question are summarized in the following:

Q1) Stakeholder groups: There are currently multiple stakeholders in Switzerland across sectors actively advocating for and working on CCTS/CCUS solutions. Other stakeholders are relevant for an upscaling but not yet involved much. Figure 3 gives provides an overview of relevant stakeholder groups in Switzerland (Q1a) and internationally (Q1b). The upper cluster of Swiss stakeholders shown in the mapping is organized around the sites where carbon capture can be applied: The CO_2 point sources, i.e., point source emitters from (mainly) hard-to-decarbonize industries and bioenergy. This includes waste-to-energy, cement, biogas, waste-water-treatment, and wood-fired plants. With the umbrella term "challenge owner", we collect all public and private entities operating and/or owning point sources. In this cluster, some stakeholders fall into multiple groups, raising questions of roles and responsibilities.

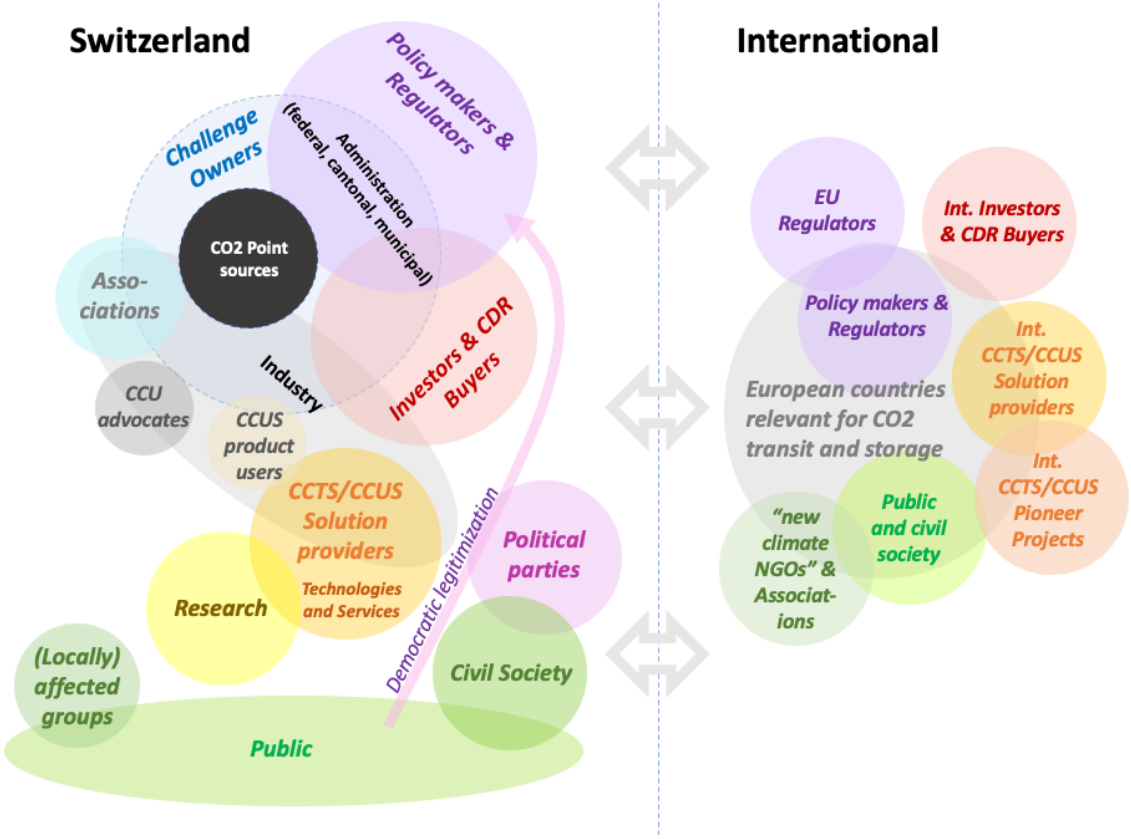

Figure 3: Stakeholder map for CCTS/CCUS in Switzerland

Note: 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 CO_2 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.

Q2) Premises: The following aspects were discussed with stakeholders to get an understanding of their premises regarding the CCTS and CCUS pathways:

- General 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 implementing the respective pathways,
- Potential determining factors and boundary conditions that could enable or block the operationalization and upscaling of the two pathways in the future.

The general premises of stakeholders towards CCTS/CCUS actively engaged in the topic do not diverge much. However, emphases on particular opportunities, challenges, as well as systemic boundary conditions differ between stakeholders.

Key perceived opportunities are:

- Technologically proven pathways to reduce and remove hard-to-abate emissions,

- Integrability in existing value chains and opportunity to use cross-sectoral synergies,
- CCTS: Potential to lead to storage of multiple megatons CO_2, covering all major points sources in Switzerland,
- CCUS: Decentralized and already operational approach suited for small point sources (e.g., biogas plants),
- Opportunity for Switzerland to take a pioneer role.

Key perceived challenges are:

- Large investment and infrastructure requirements: Especially the “chicken-or-egg problem” with regards to investments and long-term financing of CCTS is seen as a major blockade by many stakeholders,
- Lack of planning security, e.g., regarding CO_2 storage destinations and "exit points", timeline of transport infrastructure development and long-term financing (costs, CO_2 price, etc.)
- Potential competitive disadvantage for early-movers (economic punishment),
- Unaligned responsibilities and agency between public and private sectors (especially between challenge owners),
- Public support for carrying costs and for the local implementation of infrastructures.

Key perceived determining factors and boundary conditions are:

- Presence of pilot and pioneer projects to learn and showcase feasibility, costs, and side-effects,
- Regulatory clarity,
- Business models and financing schemes and de-risking mechanisms,
- Development of CO_2 prices and compliance markets (e.g., ETS),
- International integration and regulation (especially with the EU),
- Long-term security of supply of renewable energies,
- Political will and public perception.

Q3) Positions: Most experts actively engaged with the topic see no alternative to CCTS/CCUS for reaching the Swiss climate goals. Based on this premise, they position themselves as advocates of CCTS/CCUS, advocating for the topic within their organizations and towards other stakeholders, while at the same time developing solutions and basis for decision-making given yet unsolved challenges and open questions. Decision-makers who position themselves as observers and cautioners want to see proof that CCTS/CCUS makes sense both for climate mitigation and from an economic perspective. This implies that interests on very different levels need to be considered and balanced, if necessary, among others:

- Net mitigation of GHG emissions in general and globally,
- Mitigation of CO_2 emissions from a particular source or within a particular jurisdiction,
- Planning security and viability of business models for operators of point sources,
- Regulatory clarity and fair conditions for competition,
- Distributive and procedural justice regarding societal costs and impacts,
- Mitigation of adverse side-effects, e.g., on energy supply, noise emissions, air quality.

Q4) Recommendations: We derived four recommendations for the engagement with stakeholders for CCTS/CCUS-related projects. They are outlined in greater detail in a commentary paper (Eberenz & Dallo et al., submitted, c.f. section "Publications" below). The recommendations encompass the following themes:

1. Engaging pro-actively with relevant stakeholder groups,
2. Differentiating the premises, needs and concerns of advocates, observers, cautioners, and those yet more or less unfamiliar with the topic,
3. Differentiating the systemic challenge and the context of specific, local implementations – while approaching them in a coordinated manner,
4. Adapting engagement strategies over time, keeping an eye open of changing contexts and needs, as well as emerging stakeholders and interest groups.

The detailed results from subtask 2.6 are provided Appendix E – *Deliverable 5.5 – Stakeholder engagement for CCTS/CCUS in Switzerland – Stakeholder map and recommendations for stakeholder engagement.*

3.2.4 Current knowledge and public perception of the Swiss public towards CCTS/CCUS (Subtask 2.7)

The societal perspective of CCTS/CCUS recognizes that addressing climate change is a complex and multifaceted challenge. It considers not only the technical feasibility but also the broader social, environmental, economic, and ethical dimensions to ensure that CCTS/CCUS projects are implemented in a way that maximizes benefits while minimizing negative impacts on society as a whole. The main objectives of this subtask were (i) to assess the Swiss public's perception of, familiarity with, acceptance of, perceived risks and benefits, and support for the two pathways explored in DemoUpCARMA; (ii) to explore positive and negative drivers of public perception and acceptance; (iii) to identify knowledge gaps and information needs; (iv) to evaluate different communication products to provide recommendations on how to provide evidence-based information allowing people to build informed opinions about CCTS/CCUS.

The overall insights related to the two CCTS/CCUS pathways from the focus groups are the following:

- Most participants **had heard at least from one of the pathways** – but not in detail – either in the **media** (TV and newspaper) or at **work/school**.
- Participants had **many open questions** they would like to ask an expert, which reflects their **interest in the topic** (e.g., costs, energy balance, CO_2-neutrality of the transportation since the CO_2 is transported thousands of miles by truck, train, and ship to Iceland).
- Regarding the **risks** for both pathways, participants mentioned that these processes reduce the incentive to emit less CO_2 and, thus, decarbonization efforts are slowed down and sufficiency is neglected (e.g., behavioral change). Further risks mentioned by the participants were limited storage capacities, the risk of leakage, a high energy consumption, and high costs.
- The main perceived **benefit** of both pathways was that non-avoidable CO_2 emissions can be offset. Further, the CO_2 storage in concrete in Switzerland has shorter transportation ways and is a local solution, whereas the storage in Iceland might have a higher storage capacity.
- The three main take-home messages mentioned by the participants were: 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 (e.g., environmental and health impacts, safety of

the underground storage, what happens with the CO_2 in the concrete when it has to be demolished, what is the role the oil lobby); and iii) **life cycle assessment needed**, considering also the risks and benefits.

The overall insights related to the two CCTS/CCUS pathways from the online survey are the following:

- Swiss people were **not familiar with** the two pathways and CCTS/CCUS in general but are keen to learn more.
- Public acceptance and support were **driven by various personal and social factors** (e.g., people's climate change concerns, trust in different stakeholders, political orientation, age).
- For Swiss people, it was important that the **Icelandic public accepts** to store foreign CO_2 from Switzerland in their underground reservoirs in Iceland.
- Perceived benefits and risks **depended on** the specific CO_2 capture, transport, and storage **processes**.
- In addition to the risks identified in previous studies, we identified the following **risks** perceived by the public: i) political lobbying; ii) inertia of the political system, which will slow down the upscaling; iii) no incentive to emit less CO_2; iv) large natural events such as earthquakes or volcanic eruptions can lead to CO_2 leakage; v) construction industry has no incentive to reduce CO_2 footprint; and vi) neglection of sustainable substitutes (concrete pathway).
- In addition to the benefits identified in previous studies, we have identified the following **benefits** perceived by the public: 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) increased chance to reach the net-zero goals; and vi) long-term storage of the emitted CO_2 becomes possible.
- Infographics were preferred over written text for receiving information about CCTS/CCUS. Thus, communication material should **combine visual with textual information**, taking into account people's different preferences and skills.

The detailed results from subtask 2.7 are provided in Appendix F – Subtask 2.7 – *Report on the current knowledge and public perception of the Swiss public towards CCTS and CCUS.*

3.3 Results and discussion of Task 3

3.3.1 Technical regulatory gaps for CO_2 pipelines (Subtask 3.1)

The analysis has shown that the development of legislation and technical regulations for CO_2 pipelines need to be tackled with a phased approach. First, the general competences and authority for the development of legislation and technical regulations for CO_2 pipelines need to be defined. Currently, the Constitution only provides the basis for the development of legislation on energy technologies at the federal government level – for example regulations on oil and gas pipelines. However, at the federal level, there is no constitutional basis for comprehensive technical regulation of CO_2 pipelines. This leaves the government with three different options on how to approach the development of legislation and technical regulations for CO_2 pipelines:

- Option 1: Based on the currently applicable constitutional basis, the competence for the development of legislation and technical regulations for CO_2 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 CO_2 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”.

Overall, no extensive technical regulations or standards focusing on the transport of CO_2 through pipelines have been implemented in Switzerland so far. Therefore, regardless of the overarching regulatory regime that is opted for above, at some point, technical regulations specific to CO_2 pipelines will be needed to be developed – either on cantonal level or federal level.

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 CO_2-specific aspects or used as a starting point for the creation of an independent technical regulatory framework for CO_2 pipelines. More general technical regulations which typically have to be considered for the design, construction, or operation of larger infrastructure projects – for example in the area of spatial design or environmental protection – are to a large extent regulated independently of the application case and could also be applied to CO_2 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 CO_2 pipelines could be developed. For the aspects specific to CO_2 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 had a similar starting position as Switzerland: There are no comprehensive technical regulations for CO_2 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 formations for developing a technical regulatory framework for CO_2 pipelines.

The detailed analysis of subtask 3.1 are provided in Appendix G – Subtask 3.1 - *Technical regulatory gaps for the pipeline.*

3.3.2 Organizational and financial models for future CCTS infrastructure (Subtask 3.2)

The goal of this subtask was to outline and analyze organizational and financial models that could be considered for a CO_2 pipeline network infrastructure in Switzerland. For this, models of how such an investment could be organized and financed were examined in three different sets of comparable precedent cases. At first, models that are used or proposed for CO_2 pipelines in Europe were analyzed. Secondly, given the very limited amount of practical experience found in funding CO_2 pipeline infrastructure in Europe, a broader view is taken on models that have been used in Europe for similar infrastructure assets. Thirdly, models used for gas pipelines, electricity grid, water transmission networks and highways in Switzerland were analyzed. An evaluation of the results to date together with an outlook are summarized next.

A scaled-up Swiss CO_2 pipeline network is expected to require capital expenses between EUR 2.7 and 3.1 billion and to have operational expenses of around EUR 200 million per year. Although this is not an unprecedented investment in terms of size in Switzerland, the investment carries significant risks, requires concerted organizational efforts by a large number of players in Switzerland and is dependent on low cost of capital. Therefore, it should be considered that a gradual expansion of the pipeline network in several sections 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 favorable Swiss funding rates. A conservative view on the Federal Constitution assumes that such public funding would

be carried out at the cantonal rather than the federal level, but legal opinions are necessary to clarify this matter. If this is indeed the case, the main challenge will be to coordinate actions and funding among the cantons.

The assessment of the three different sets of precedent cases for organizational and financial models shows that, overall, regulated business models with a central operating entity seem to provide the most suitable funding approach for a Swiss CO_2 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, adapting existing regulated business models to the case of a CO_2 transportation network requires careful consideration. Questions on how to determine the authorized operational expenses 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. 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.

The detailed analysis of subtask 3.2 are provided in Appendix H – Subtask 3.2 - *Organizational and financial models for future CO_2 infrastructure.*

4 Conclusions

Unlocking the path to breakthroughs: paving the way for scalable carbon revenues in CCUS (Subtask 1.1 – 1.3)

Though it might often seem so from the outside, breakthroughs – whether in technology or in social, economic, and political realms – do not happen overnight but result from continuous efforts addressing bottlenecks and capitalize on opportunities. Ensuring that carbon revenue certainty matches the investment risks and costs that private sector actors face is paramount. In the area of WP 5 task 1 the contribution of DemoUpCARMA to breakthroughs in achieving scalable carbon revenues that enable a functioning business model for various forms of CCTS/CCUS, has been in the examination of likely bottlenecks in the broader carbon-revenue landscape about regulation and carbon markets' limitations with a view to developing a suite of quantification tools for the adoption of many different CCTS/CCUS value-chains in carbon markets and beyond as well as stepwise guidance for industry actors to unlock these sources of revenue.

Using the Swiss ETS to incentivize CCTS/CCUS scaling up (Subtask 1.4)

The integration of CCTS/CCUS into the ETS, coupled with free allocation, presents challenges regarding compliance with WTO subsidy rules. Yet, the existing price of allowances (even with adjustments) falls significantly short of the costs involved in implementing CCTS/CCUS within the Swiss ETS installations, hindering necessary investments. De-risking tools like Carbon Contracts for Differences (CCfD) could facilitate CCTS/CCUS adoption within ETS installations while adhering to WTO obligations. Additional proceeds than those coming from the auctioning of Swiss ETS allowances (e.g., raised by a Swiss CBAM revenues in case it will be implemented) would be necessary to cover up existing needs for funding in the short- to mid-term; in the mid- to long-run, however, such instrument carries the potential for the government to recuperate assumed costs, provided the price of ETS allowances continues to rise.

CCTS/CCUS investment and financing needs (Subtasks 2.1-2.2)

This subtask addresses the costs associated with different financing structures for CO_2 transport and the influence of support policies. Public financing proves to be the most cost-effective. Yet, capital-intensive pipelines are significantly affected by the choice of financing structure. In contrast, rail transportation costs show minimal differences as a function of funding. Despite the cost advantage of public financing, operational efficiencies or historical precedents in certain regions could favor other options. Policies can bridge the cost gap between private and public funding but involve trade-offs.

Public acceptance of support policies (Subtask 2.3-2.5)

Public acceptance of CCTS/CCUS and CDR including biogenic CCTS/CCUS also hinges on the policies used to incentivize them. Regulations that aim for durable CO_2 storage and reduce uncertainty connected to CO_2 storage can increase public support even if they increase the costs for consumers. This indicates that citizens will be more willing to endure the costs connected to a CCTS/CCUS and CDR including biogenic CCTS/CCUS scale-up if policy designs aim to ensure the long-term effectiveness of CO_2 storage. Besides regulations for CO_2 storage, we also study how the Swiss public perceives CO_2 exporting. We find that public support depends on whether the country that imports Swiss CO_2 is perceived as reliable and whether risks for the public can be minimized. This means citizens view the export of CO_2 more favorably if an import country is democratic and takes climate change mitigation seriously. Storage sites close to citizens in the importing country as well as public opposition against CO_2 storage in the importing country can however lead to lower levels of public support.

Stakeholder engagement for CCTS/CCUS in Switzerland (Subtask 2.6)

While CCUS is seen by stakeholders as a flexible and operational solution for small point sources, stakeholders perceive CCTS as suitable for large point sources, but challenged in moving beyond the concept stage. The upscaling requires coordinated engagement across sectors to ensure planning security and clarify responsibilities and mandates. A step-by-step upscaling moving from smaller to larger projects is perceived as a promising way forward, as pilot and pioneer projects provide the opportunity to learn, while at the same time showcasing feasibility, costs, co-benefits, and side-effects. In the highly dynamic context, policy makers, regulators and implementers should acknowledge that it is currently mainly experts and advocates of CCTS/CCUS who position themselves in discussions around CCTS/CCUS. Once the implementation of large-scale and costly CCTS/CCUS starts “getting real”, more previously unaffected stakeholders (and the general public, see subtask 2.7) need to get involved.

Current knowledge and public perception of the Swiss public towards CCTS/CCUS (Subtask 2.7)

Public familiarity with CCTS/CCUS is rather low, thus efforts are needed to provide evidence-based information allowing people to build informed opinions. To this end, regular assessments of public perception is key to identify their concerns, information needs, and tipping points (e.g., experiencing the effects of climate change might increase the urgency of CCTS/CCUS). Moreover, when cross-border CCTS/CCUS options are discussed/decided upon, it is vital to involve all affected societies, making sure that public acceptance is given in all countries.

5 Outlook and Next Steps

Ensuring successful implementation of CCUS initiatives (Subtask 1.1 – 1.3)

To ensure the success of CCTS/CCUS initiatives, it is important that public and private actors continue ongoing work and build on cooperation strategically:

- VCS is set to finalize and adopt of the remaining methodology modules and any additional guidance notes in 2024 (developed under the CCS+ Initiative). This step is crucial in establishing a standardized framework for monetizing results from the implementation of CCTS/CCUS activities in carbon markets.
- Watch the ongoing development and maturation of the CRCF. Monitoring its progress and emergence of its requirements allows assessing the potential eligibility of specific CCTS/CCUS activities and striving toward alignment in project planning.
- Stay informed about forthcoming foundational decisions regarding the ETS, with a particular focus on the potential inclusion of the waste sector and regarding the treatment of biomass. The latter is relevant to anticipate how carbon removal may be monetized inside or outside the ETS, which can significantly influence the feasibility and success of prospective CCTS/CCUS business cases.
- Closely follow the development of CCTS/CCUS mitigation projects made possible by unused funds from the Climate Cent Foundation. Valuable lessons can be learnt from the five domestic and international value chain projects.

Actors involved in CCTS/CCUS value chains can take proactive steps towards initiating VCM projects – be it under the Gold Standard, Puro Earth, or the VCS – immediately.

Potential strategies to acknowledge emissions reductions achieved through CCTS/CCUS by emitters participating in the Swiss ETS (Subtask 1.4)

Università della Svizzera Italiana will continue monitoring law and policy developments affecting the Swiss and EU ETS and related instruments such as the EU CBAM and CCfD for the purposes of integrating CCTS/CCUS more effectively and in full compliance with international obligations. With a view to contributing to the next revision of the CO_2 Act for the time after 2030, it will further refine and validate findings presented on the various options available to strengthen the Swiss ETS' role in triggering investment in CCTS/CCUS, including further suggestions on potential sources of financing of the proposed instruments, and finalize the results in an academic publication.

CCTS/CCUS investment and financing needs (Subtasks 2.1-2.2)

In preparation for an academic publication, the next steps will include conducting further semi-structured interviews. These interviews aim to validate our current financing assumptions, assess the suitability of each financing structure for different transport modes, and identify any possible limitations. The newly acquired data will be integrated into our techno-economic model to evaluate how each financing structure impacts the LCOT for each mode of transport. The academic paper will be submitted in Q4/2023-Q1/2024.

Subsequently, we are planning to further validate our findings through a workshop. The goals of the workshop are twofold: a) to collect feedback from prospective investors regarding the financing sources and b) to discuss the practicality of implementing the analyzed policy scenarios. This workshop will either be conducted online or in person, potentially in collaboration with another organization (e.g., ETH Carbon Removal Lab; Swiss Carbon Removal Platform (CDR Swiss)).

Stakeholder engagement for CCTS/CCUS in Switzerland (Subtask 2.6) & Current knowledge and public perception of the Swiss public towards CCTS/CCUS (Subtask 2.7)

Stiftung Risiko-Dialog will continue their stakeholder engagements in the topic within the CDR Swiss and to accompany pilot and implementation projects in the field, enabling implementers to make the best use of the recommendations and insights from DemoUpCARMA. Based on the recommendations for stakeholder engagement and public communication, this involves (1) strategic engagement with challenge owners, as well as civil society, on the national and regional level, (2) processing and dissemination of important information for the public and decision-makers, and to (3) engage locally affected stakeholders groups proactively and involve them in decision processes early on.

It should be noted that normative (ethical) aspects as well as the relationships and power structures between stakeholders were not the focus of subtask 2.6. These two issues should receive further attention in theory and practice, especially when it comes to the fair distribution of burdens (e.g., costs) and other social and environmental impacts of implementations of CCTS/CCUS.

ETH-SED (2.7) and the Stiftung Risiko-Dialog (2.6) will merge their lists of recommendations for public communication and stakeholder engagement for a publication, which should support institutions responsible for public campaigns and outreach activities to effectively interact with and inform societal stakeholders including the general public about CCTS/CCUS. They will be submitted for publication as a Commentary (see section Publications below). The work of ETH-SED will further continue in the sister project DemoUpStorage.

6 National and international cooperation

Enhancing CCUS through international cooperation (Subtasks 1.1 – 1.3)

International cooperation is crucial for comprehending the implications of the CRCF for Swiss CCTS/CCUS entities. Should the EU ETS adopt regulatory changes with some lead time compared to the corresponding change in the Swiss ETS, this would allow watching the implementation practice and opportunities for CCTS/CCUS with relevant lessons especially for Swiss waste sector entities and other entities (also in the cement sector) regarding the potential inclusion of biomass. Waste and cement actors could thus benefit from proactive engagement with their counterparts in the EU.

Furthermore, there is a need for cooperation at the state level, intending to establish bilateral agreements on the foundational aspects of transboundary CCTS/CCUS activities. This cooperation should focus on issues such as ownership rights and the accounting of mitigation results, as these factors have significant implications for the design and execution of carbon projects. This collaborative approach will be instrumental in advancing and ensuring the success of carbon removal and utilization efforts.

CCTS/CCUS investment and financing needs (Subtasks 2.1-2.2)

This subtask builds on the techno-economic work on CO_2 transport in Switzerland from WP4 by Oeuvray et al. (2023). Although we are modelling the economics of CO_2 transport in Europe, these two works are very synergistic as the transport of CO_2 from Switzerland to storage sites in Europe will be of great importance in the coming years. The expert interviews conducted have contributed significantly to modelling the European CO_2 transport market as realistically as possible. Further cooperation with the ETH Carbon Dioxide Removal Lab or the Risk Dialogue Foundation.

Stakeholder engagement for CCTS/CCUS in Switzerland (Subtask 2.6)

Synergies were achieved with Subtask 2.7, as well as with CDR Swiss, a multi-stakeholder platform initiated and lead by Stiftung Risiko-Dialog Carbon Dioxide Removal Options: Policies and Ethics (CDR-PoEt), funded by the German Federal Ministry for Education and Research (BMBF). In the working groups of CDR Swiss, perspectives and systemic challenges on the pathways demonstrated with DemoUpCARMA were discussed with diverse stakeholders from Switzerland. As part of CDR-PoEt, Risk Dialogue conducted topical online 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.

Current knowledge and public perception of the Swiss public towards CCTS/CCUS (Subtask 2.7)

The work will continue in the sister project DemoUpStorage, where we will conduct a media content analysis, interviews and focus groups with relevant stakeholders, and a public survey. We will then conduct a cross-cultural comparison to identify differences between Swiss and Icelandic public perceptions and acceptance of CO_2 stored underground.

7 Publications

Dallo, I., Marti, M., Kuratle, L. D., Công, L., Zeller, S., & Zaugg, S. (2023). Carbon capture, transportation, utilization, and storage - the societal perspective. [*ready for submission to Energy Research & Social Science*]

Eberenz, S., Dallo, I., Marti, M., Becattini, V., Holenstein, M., Wiemer, S. & Mazzotti, M. (submitted). Commentary: Engaging with the public and stakeholders for carbon capture, transportation, utilization, and storage – nine recommendations. [*submitted as a Commentary to International Journal of Greenhouse Gas Control]*

Honegger, M. (2023). Toward the effective and fair funding of CO2 removal technologies. Nature Communications. 14, 534.

Michaelowa, A., Honegger, M., Poralla, M., Winkler, M., Dalfiume, S., & Nayak, A. (2023). International carbon markets for carbon dioxide removal. *PLOS Climate, 2*(5).

Oh, S., Eberenz, S., Honegger, M., Wallis, O., et al. (in preparation) Unpacking BECCS and DACCS: Actor interests and power dynamics in CCS, BECCS and DACCS. [in preparation]

Rhein, S., Bernauer, T. (2024). Citizens want effective long-term solutions to climate change, but at what price? Insights from a choice experiment on carbon removal standards. [in preparation for submission]

Rhein, S., Bernauer, T. (2024). Our waste in their backyard or not?
Regime type and citizens' preferences for exporting captured CO2. [in preparation for submission]

Sievert, K., Stefanescu, A., Oeuvray, P., Steffen, B. (2024). The impact of financing structures on the cost of CO_2 transport. [*in preparation to be submitted to Energy Economics]*

8 References

Braun, C. (2017) Not in My Backyard: CCS Sites and Public Perception of CCS: NIMBY and CCS Sites. *Risk Analysis* 37, 2264–2275.

Brunsting, S. *et al.* (2011) Stakeholder Participation Practices and Onshore CCS: Lessons from the Dutch CCS Case Barendrecht. *Energy Procedia* 4, 6376–6383.

Cox E., Spence E. and Pidgeon N. (2020) Public Perceptions of Carbon Dioxide Removal in the United States and the United Kingdom. *Nature Climate Change* 10, 744–749.

Duetschke E. *et al.* (2014) Does It Make a Difference to the Public Where CO2 Comes from and Where It Is Stored? *Energy Procedia* 63, 6999–7010.

Dütschke E. (2011) What Drives Local Public Acceptance–Comparing Two Cases from Germany. *Energy Procedia* 4, 6234–6240.

Dütschke E. *et al.* (2016) Differences in the Public Perception of CCS in Germany Depending on CO2 Source, Transport Option and Storage Location. *International Journal of Greenhouse Gas Control* 53, 149–159.

Huijts N., Midden C. and Meijnders A. (2007) Social Acceptance of Carbon Dioxide Storage. *Energy Policy* 35, 2780–2789.

Jobin M. and Siegrist M. (2020) Support for the Deployment of Climate Engineering: A Comparison of Ten Different Technologies. *Risk Analysis* 40, 1058–1078.

Kraeusel J. and Möst D. (2012) Carbon Capture and Storage on Its Way to Large-Scale Deployment: Social Acceptance and Willingness to Pay in Germany. *Energy Policy* 49, 642–651.

Krause R. *et al.* (2014) “Not in (or Under) My Backyard”: Geographic Proximity and Public Acceptance of Carbon Capture and Storage Facilities: Not in (or Under) My Backyard. *Risk Analysis* 34, 529–540.

L′Orange Seigo S., Dohle S. and Siegrist M. (2014) Public Perception of Carbon Capture and Storage (CCS): A Review. *Renewable and Sustainable Energy Reviews* 38, 848–863.

Offermann-van Heek J. *et al.* (2018) Trust and Distrust in Carbon Capture and Utilization Industry as Relevant Factors for the Acceptance of Carbon-Based Products. *Frontiers in Energy Research* 6, 73.

Pianta S., Rinscheid A .and Weber E. (2021) Carbon Capture and Storage in the United States: Perceptions, Preferences, and Lessons for Policy. *Energy Policy* 151, 112149.

Tcvetkov P., Cherepovitsyn A. and Fedoseev S. (2019) Public Perception of Carbon Capture and Storage: A State-of-the-Art Overview. *Heliyon* 5, 2845.

Wenger, A., Stauffacher, M. and Dallo, I. (2021) Public Perception and Acceptance of Negative Emission Technologies – Framing Effects in Switzerland. *Climatic Change* 167, 53.

9 Appendix

Appendix A1 - Subtask 1.1 - Inception report

Appendix A2 - Subtask 1.1 - Briefing note - Climate finance landscape assessment

Appendix A3 - Subtask 1.1 - Stakeholder engagement

Appendix A4 - Subtask 1.1 - Strategy paper - Enabling CCTS and CCUS value chains for Swiss climate neutrality

Appendix B - Subtask 1.2 - CCS+ introduction methodological work

Appendix C1 - Subtask 1.3 - Blueprint 1 - Domestic CCUS value chain - Biogas upgrading capture with storage in concrete in Switzerland

Appendix C2 - Subtask 1.3 - Blueprint 2a - International CCUS collaboration - Swiss solid waste CO2-capture for storage

Appendix C3 - Subtask 1.3 - Blueprint 2b - International CCS collaboration – Swiss CO2 capture on a cement plant and storage in Iceland

Appendix C4 - Subtask 1.3 - Blueprint 3 - Abroad CCUS value chain – Biogas upgrading capture with utilization in concrete

Appendix D - Subtask 1.4 - Making the Swiss Emission Trading Scheme Work for CCS A Legal Analysis

Appendix E – Subtask 2.6 - Stakeholder Engagement for CCTS and CCUS in Switzerland

Appendix F – Subtask 2.7 - Report on the current knowledge and public perception of the Swiss public towards CCTS and CCUS

Appendix G – Subtask 3.1 - Technical regulatory gaps for the pipeline

Appendix H – Subtask 3.2 - Organizational and financial models for future CO2 infrastructure