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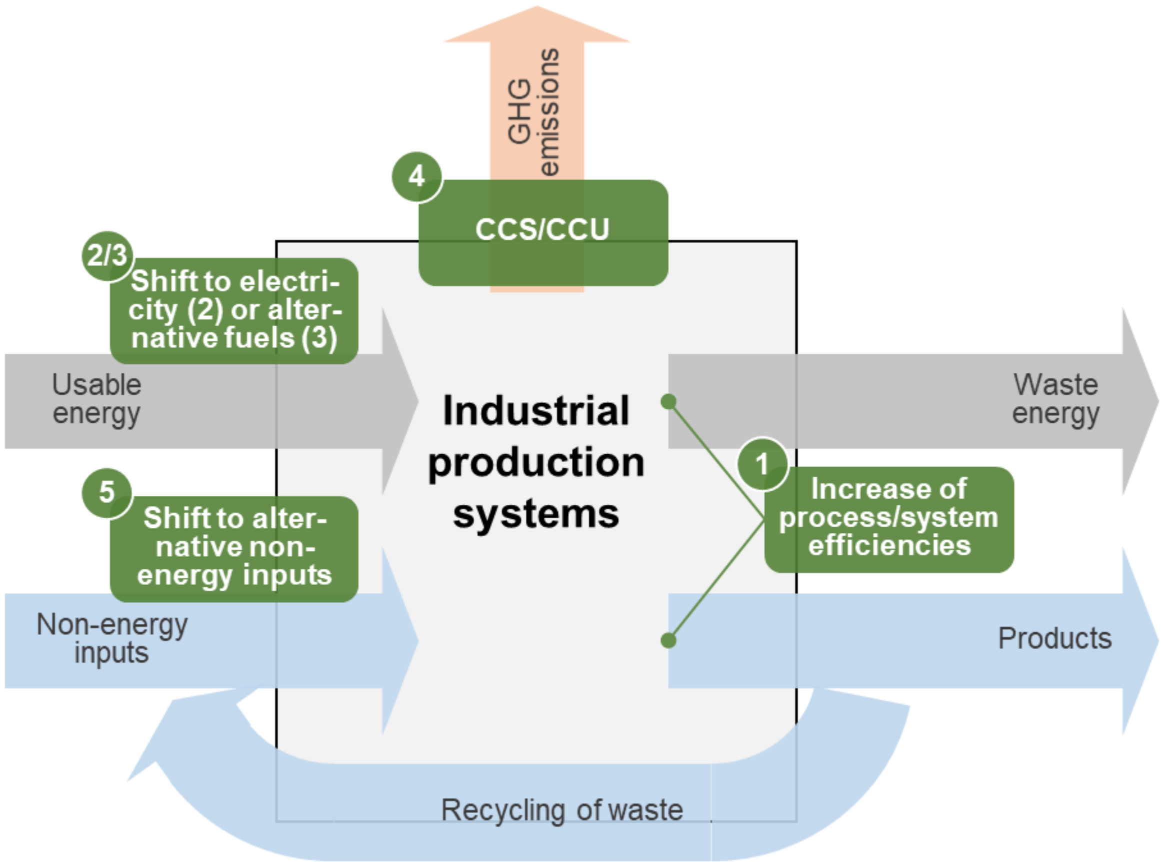
Federal Department of the Environment, Transport, Energy and Communications DETEC

Swiss Federal Office of Energy SFOE
Energy Research and Cleantech Division

Interim report dated 5 November 2021

DECARBIN

The impact of energy and climate policy on the decarbonization of industry in Switzerland



Source: DECARBIN 2021

Date: 5 November 2021

Location: Bern

Publisher:
Swiss Federal Office of Energy SFOE
Energy Research and Cleantech
CH-3003 Bern
www.bfe.admin.ch

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SFOE contract number: SI/502114-01

Zusammenfassung

Der Industriesektor trug 2018 rund 18% zu den Schweizer CO2-Emissionen bei. Die Technologien zur drastischen Reduktion der Emissionen in emissions- und energieintensiven Industrien stecken aber weitgehend noch in den Kinderschuhen. Gleichzeitig sind diese Industrien für die Schweizer Wirtschaft von grosser Bedeutung. Grosse Schweizer Unternehmen sind in emissionsintensiven Sektoren wie Zement, Spezialchemie oder Pharma tätig. Weiter kann die wirtschaftliche Attraktivität und damit der Einsatz dieser neuen, emissionsarmen Technologien das Schweizer Energiesystem stark beeinflussen. Daher ist es eine wichtige Aufgabe für die Schweizer Politik, den Übergang zu einer kohlenstoffarmen Industrie effizient zu gestalten, ohne dabei den wirtschaftlichen Wohlstand, die Versorgungssicherheit und den sozialen Zusammenhalt in der Schweiz zu gefährden. Die Ergebnisse des DECARBIN Projekts werden eine evidenzbasierte Gestaltung von Politikmassnahmen unterstützen in diesem wichtigen, aber wenig erforschten Bereich der Energie- und Klimapolitik. Bisher wurde im Projekt eine Sektor-Technologie-Matrix entwickelt, die zusammenfasst, welche Optionen aus technologischer Sicht am besten geeignet sind, die emissionsintensivsten Industriesektoren in der Schweiz – Baustoffe (einschliesslich Zement), Chemie & Pharma, Metalle und Lebensmittel – zu dekarbonisieren. Dabei wurden die Vermeidungsoptionen entlang von fünf Gruppen gegliedert: (1) Erhöhung der Prozess-/Systemeffizienz, (2) Umstellung auf strombasierte Prozesse (Elektrifizierung), (3) Umstellung auf alternative Brennstoffe, (4) Kohlenstoffabscheidung und -speicherung (CCS) oder -nutzung (CCU) und (5) Umstellung auf alternative nicht-energetische Ausgangsstoffe.

Summary

Industry contributed about 18% of Swiss CO2 emissions in 2018 but technologies for drastically reducing emissions in carbon- and energy-intensive industrial production are largely still in their infancy. At the same time, these industries are of significant importance for the Swiss economy. Major Swiss companies are engaged in industrial production in subsectors such as cement, specialty chemicals or pharmaceuticals. Moreover, the economic attractiveness and hence the deployment of these new, low-carbon technologies can strongly affect the Swiss energy system. Hence, managing the low-carbon transition of emitting industries effectively, without jeopardizing economic prosperity, security of supply and social cohesion, is a momentous task for Swiss policymakers. As such, the DECARBIN project results will support evidence-based policymaking in this important but little-researched domain of energy and climate policy. So far, the project has developed a sector-technology matrix summarizing which options are best suited (from a technological point of view) to decarbonise the most emission-intense industry sectors in Switzerland, i.e. the minerals (including cement), chemicals, metals and food sectors. Abatement options were structured along five groups: (1) Increase of process/system efficiencies, (2) shift towards electricity-based processes (electrification), (3) shift towards alternative fuels, (4) carbon capture and storage (CCS) or use (CCU), and (5) shift to alternative non-energy inputs.

Contents

Abbreviations

CCS – Carbon capture and storage

CCU – Carbon capture and use

EU ETS – EU Emissions Trading System

GHG – Greenhouse gas

PIK – Potsdam Institute for Climate Impact Research

SCCER CREST – Competence Center for Research in Energy, Society and Transition

SCCER EIP – Swiss Competence Center for Energy Research, Efficiency in Industrial Processes

SCCER HaE – Swiss Competence Center for Energy Research, Heat and Electricity Storage

SFOE – Swiss Federal Office of Energy

UNFCCC – United Nations Framework Convention on Climate Change

WP – Work package

1 Introduction

1.1 Background information and current situation

The Federal Council aims to achieve a climate-neutral Switzerland by 2050 (Bundesrat, 2019). While the decarbonization of the transport and building sectors is under way in Switzerland (Bundesrat, 2021) and in many other industrialized countries, technologies for drastically reducing emissions in carbon- and energy-intensive industrial production are largely still in their infancy. Industry contributed about 18% of Swiss CO2 emissions in 2018 (BAFU, 2020a) and consumed about 20% of final energy in Switzerland in 2020 (BFE, 2021). At the same time, carbon- and energy-intensive industries are of significant importance for the Swiss economy. Major Swiss companies are engaged in industrial production in subsectors such as cement, specialty chemicals, pharmaceuticals, metals, and machinery. Hence, managing the low-carbon transition of emitting industries effectively, without jeopardizing economic prosperity and social cohesion, is a momentous task for Swiss policymakers.

To date it remains unclear, which options exist for deep decarbonization of Swiss industries and how these are affected by energy and climate policy. Efficiency enhancing measures (as studied in the SCCER EIP – Efficiency of Industrial Processes) are an important part of the transition pathway, but they cannot deliver the full decoupling of industrial production from carbon emissions. The main technological options to this end are (1) Increase of process/system efficiencies, (2) shift towards electricity-based processes (electrification), (3) shift towards alternative fuels, (4) carbon capture and storage (CCS) or use (CCU), and (5) shift to alternative non-energy inputs. The economic viability of these decarbonization options is strongly affected by energy and climate policies, and the international competitiveness of Swiss industrial production depends on the design of such policies (Dröge et al., 2009).

At the same time, the economic attractiveness and hence the deployment of these options can strongly affect the Swiss energy system (see e.g. Agora Energiewende (2019) for the case of Germany) and the Energy Strategy 2050. For example, in case many industry processes are electrified, the electricity demand from industry might rise substantially, whereas deployment of CCS could increase their natural gas demand and the need for a dedicated infrastructure for CO2 transport. In other words, Swiss energy and climate policy will affect industry decarbonization, which in turn will affect the energy system. To date, however, it remains unclear to which extent and in which way (for instance, combining these options with energy efficiency measures might mitigate the effects). In the DECARBIN project, we will uncover these effects and develop recommendations on policy mix designs that effectively and efficiently induce a decarbonization of the Swiss GHG emitting industry sectors while avoiding unintended negative feedbacks on the Swiss energy system. As such, the DECARBIN project results will support evidence-based policymaking in this important but little-researched domain of energy and climate policy.

While the research questions in the DECARBIN project have not been addressed before, we can still build on previous research. For a long time, the industrial sector received little attention with respect to reaching climate goals in Switzerland – e.g., the Swiss marginal abatement cost study of 2009 (McKinsey, 2009) did not calculate abatement costs for industry. In the 2nd phase of the SCCER since 2017, research from the competence centre for Efficiency in Industrial Processes (EIP) assessed the techno-economic feasibility of efficiency options in industry, for example efficiency measures for Swiss industrial motor systems (Zuberi et al., 2017), the Swiss cement industry (Zuberi & Patel, 2017a), the Swiss metals industry (Bhadbhade et al., 2019), the Swiss chemical and pharmaceutical industry (Zuberi & Patel, 2019), and the Swiss food & beverages industry (Bhadbhade & Patel, 2020). Such efficiency measures are an important part of the transition pathway, but they cannot deliver the full decoupling of industry production from carbon emissions. DECARBIN therefore plans to build on SCCER EIP results and extend the analysis to technologies that are relevant for a deep decarbonization in the mid- to long-term. For Switzerland, these technological options have only partially been analysed, e.g. CCS in cement within SWIDEM and SCCER EIP (Obrist et al., 2021; Zuberi & Patel, 2017b) and technologies along the "power-to-x" path in a study commissioned by Innosuisse and the SFOE (Kober et al., 2019).

On the international level, the systematic assessment of industry decarbonization also started only recently (with the exception of earlier studies on CCS in steel and cement industries (see e.g. Kajaste & Hurme, 2016; Van Ruijven et al., 2016)). Several overviews of technology options have recently been published (Agora Energiewende, 2019; C. Bataille et al., 2018; C. G. F. Bataille, 2019; BMWi, 2020; Levesque et al., 2020; PBL Netherlands Environmental Assessment Agency, 2021; Wesseling et al., 2017). The impact on the energy vector has also been analysed (Gierkink et al., 2021; Lechtenböhmer et al., 2016). These studies, however, cover industry sectors that are relevant for other geographies (including aluminium, steel, etc.), with a focussed analysis of relevant options and cost for the emitting industry sectors in Switzerland still pending. To quantitatively assess technology options for Switzerland, we will therefore build on our solid experience in techno-economic modelling (compare e.g. Schmidt et al., 2019), using the concept of abatement costs (Schmidt et al., 2012) that has recently been applied for industry decarbonization technologies in the German study by Agora Energiewende (2019).

The analysis of policy mixes finally will build on a broad literature of climate policy mixes for energy technologies, including previous work of the authors (see e.g. Polzin et al., 2019; Schmidt & Sewerin, 2019). Important streams of the literature analyse how policy instruments are most efficiently combined to policy mixes (Kern & Howlett, 2009; Rogge & Reichardt, 2016; Schmidt & Sewerin, 2019), and how specific design calibrations affect the outcomes of policy instruments (Howlett, 2009; Polzin et al., 2019).

Literature in environmental economics considers the issue of climate and energy policies affecting the competitiveness of regulated industries and thereby leading to "carbon leakage" to less-regulated geographies (see e.g. Böhringer et al., 2017; Ismer & Neuhoff, 2007; Naegele & Zaklan, 2019), with a particular focus on the linking on cap-and-trade emission trading systems as done only recently for the Swiss and the EU systems (Green, 2017; Ranson & Stavins, 2016). While previous research in the field empirically mostly studied the United States and the European Union, policy design principles derived from those geographies will inform the analysis for the Swiss context in DECARBIN.

1.2 Purpose of the project

While decarbonization of the industry sector is arguably much harder than the decarbonization of other sectors (e.g., electricity generation, transport), the eventual decoupling of industry production is imperative in order to reach net zero in 2050. Thus far, literature on industry decarbonization, the link to the energy sector, and the role of policy is very limited, particularly for the case of Switzerland. This leaves Swiss policy makers with a high level of uncertainty, and risks taking uninformed policy decisions that may have unintended negative consequences for the Swiss energy system.

The DECARBIN project aims to address this very gap and to assist Swiss policy makers in designing an efficient energy and climate policy mix specifically for the decarbonization of the Swiss industry sector. To this end, our work shall help to understand the effects of different energy and climate policies on competing industry sector decarbonization options; to assess how specific policy designs would affect the international competitiveness of Swiss industrial production plants vis-à-vis production plants in the European Union, and to estimate how a large-scale deployment of industry decarbonization technologies would in turn affect the Swiss energy system and the Energy Strategy 2050.

1.3 Objectives

To address this gap, we pose the following three research questions:

1. Which technological decarbonization options are most relevant for carbon-intensive industry sectors in Switzerland?

The industry sector in Switzerland differs structurally from the industry sector in other countries (e.g., France, Germany), and a clear understanding of relevant decarbonization options for the industry sub-sectors most pertinent in Switzerland today and in the long-term is a prerequisite for meaningful policy advice. Extending the work from SCCER EIP by further technological options that will become relevant through 2050, a sector-technology matrix will form the basis for subsequent analyses, and can also inform the energy policy debate towards net zero 2050 in Switzerland more generally.

2. How sensitive are these options' abatement costs towards energy and climate policies?

From a policy point of view, it is crucial to understand how different decarbonization options are affected by energy and climate policy choices. The key variable in that regard are abatement costs, i.e. the cost per ton CO2 reduction. The abatement cost of options such as electrification, CCS, alternative fuel-based processes etc. depend on various energy policy parameters, and DECARBIN will highlight the most important dependencies in that regard.

3. How would different climate and energy policy mixes affect the competition between industry decarbonization options, the international competitiveness of industrial production in Switzerland, and what does this imply for Switzerland's energy system?

Building on the results concerning the first two questions, DECARBIN will put great emphasis on analysing the outcome of policies with respect to technology choices, industry competitiveness, and energy system implications. Ultimately, Swiss policy makers need to know the effect of policy mixes (consisting of energy policies, general climate policies, and potentially industry-specific decarbonization policies) in the context of the Energy Strategy 2050. Concerning industry decarbonization, the project will in detail analyse three aspects: How do policy mixes affect the competition between the different decarbonization options in relevant industry subsectors, how do specific policy designs affect the competitiveness of Swiss industrial production on a European level, and what do policy mixes – and the subsequent deployment of decarbonization technologies – imply for the Swiss energy system at large.

In general, DECARBIN will combine quantitative methods (especially techno-economic modelling) with qualitative methods (technology expert interviews, policy design analysis) that allow to answer the scientific questions asked. Taken together, answering the scientific questions posed by DECARBIN shall not only advance the academic literature, but directly support evidence-based policymaking in this important but little-researched domain of energy policy.

2 Procedures and methodology

The DECARBIN project is coordinated by Prof. Schmidt and Prof. Steffen. In addition, a PhD student was hired at the beginning of the project (April 1st, 2021). The respective job ad has been published through ETH Zurich's job board and advertised internationally. In total we received applications from more than 80 candidates. Since then, two students joined the DECARBIN team for their theses: (1) a machine learning-based bibliographic analysis of industry decarbonization research, and (2) an analysis of the influence of energy and climate policy on CO2 abatement cost of selected industrial processes. Both student projects will be completed in 2022.

The DECARBIN project is structured in three work packages (WPs) with this reported being commissioned at the end of work package 1 (cf. Figure 1).

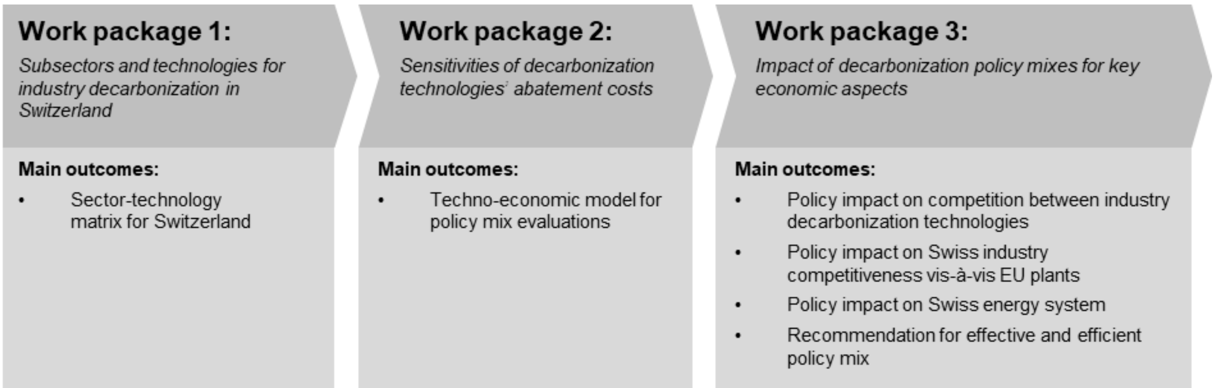

Figure 1 DECARBIN work packages

The results from each work package are subject to quality control. In the case of WP1, earlier versions of the technology-sector matrix, i.e. the prioritized industry sectors and the abatement options, were discussed by the authors' research groups. In addition, the DECARBIN project introduced an advisory board, in order to ensure a high quality of the work, to efficiently leverage existing research, and to simplify collaborations. The first advisory meeting took place on 9 September 2021. On top of the authors, four members participated in the meeting:

- Dr. Tom Kober (Paul Scherrer Institut)
- Prof. Dr. Marco Mazzotti (ETH Zurich, Department of Mechanical and Process Engineering)
- Dr. Michael Pahle (Potsdam Institute for Climate Impact Research)
- Prof. Dr. Martin Patel (University of Geneva)

In addition, the current progress and preliminary results were presented to the representatives of the SFOE on 28 September 2021. Written feedback from the SFOE on the work is expected in early November. WP 1 results, i.e. the developed sector-technology matrix, will be submitted to the SFOE latest on November 26 unless otherwise agreed. The authors plan to publish the sector-technology matrix after further improvements via the ETH Research Collection in 2022.

3 Activities and results

As part of WP 1 we developed a matrix of emitting industrial sectors and the decarbonization options most relevant for reaching net zero emissions in Switzerland (sector-technology matrix, cf. Figure 2). The matrix is a novel contribution for the Swiss context, and forms the basis for modelling and analysis in WPs 2 and 3.

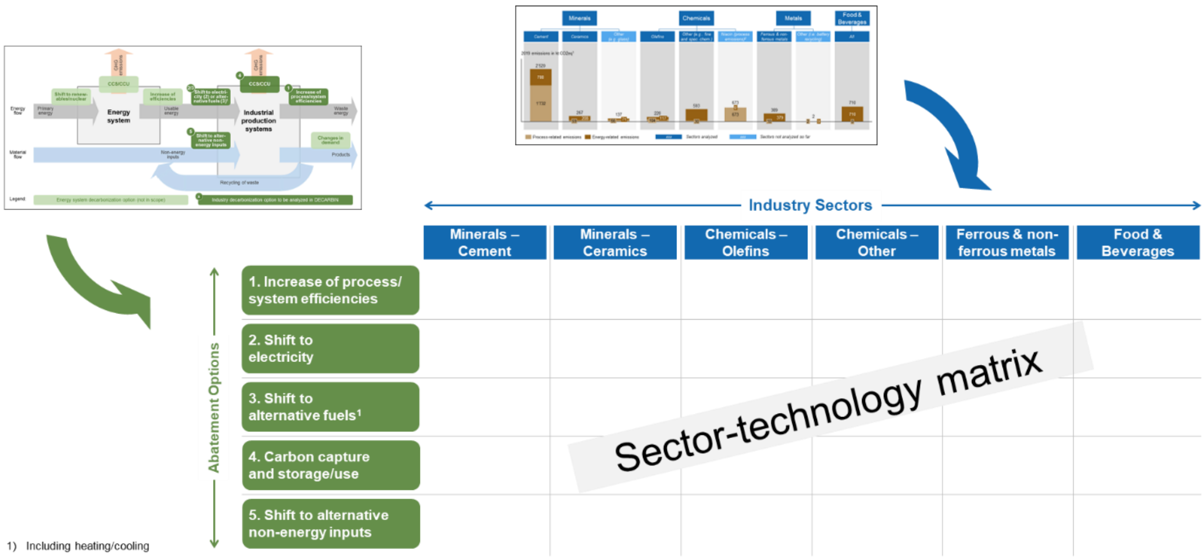

Figure 2 Construction of sector-technology matrix based on DECARBIN framework and sector prioritization

First, using statistical data on emissions from the Swiss UNFCCC reporting tables for 2019 (UNFCCC, 2021) we prioritized subsectors with a major contribution to direct emission (i.e. scope 1 emissions) in Switzerland. Of all emissions reported as part of the relevant UNFCCC categories 1A2 (Energy > Fuel Combustion > Manufacturing Industry & Construction) and 2 (Industrial Processes and Product Use) we only considered sufficiently classified emissions that are emitted on site during the production process (cf. Figure 3). Furthermore, we de-prioritized subsectors if their yearly emissions did not exceed 100 kt CO2eq. We also explicitly de-prioritized process emissions associated with the production of the food supplement Niacin, as they will be largely mitigated by the installation of a catalyst in the near future (BAFU, 2020b). This left us with four prioritized industry sectors: (1) minerals (i.e. cement and ceramics), (2) chemicals (i.e. olefins and other chemicals and pharmaceuticals), (3) metals, and (4) food & beverages (cf. Figure 4). The indicated emissions, however, are subject to uncertainty as energy-related emissions (category 1A2) and process-related emissions (category 2) are reported in different product/sector groups and energy related emissions thus had to be allocated to industry sectors based on assumptions.

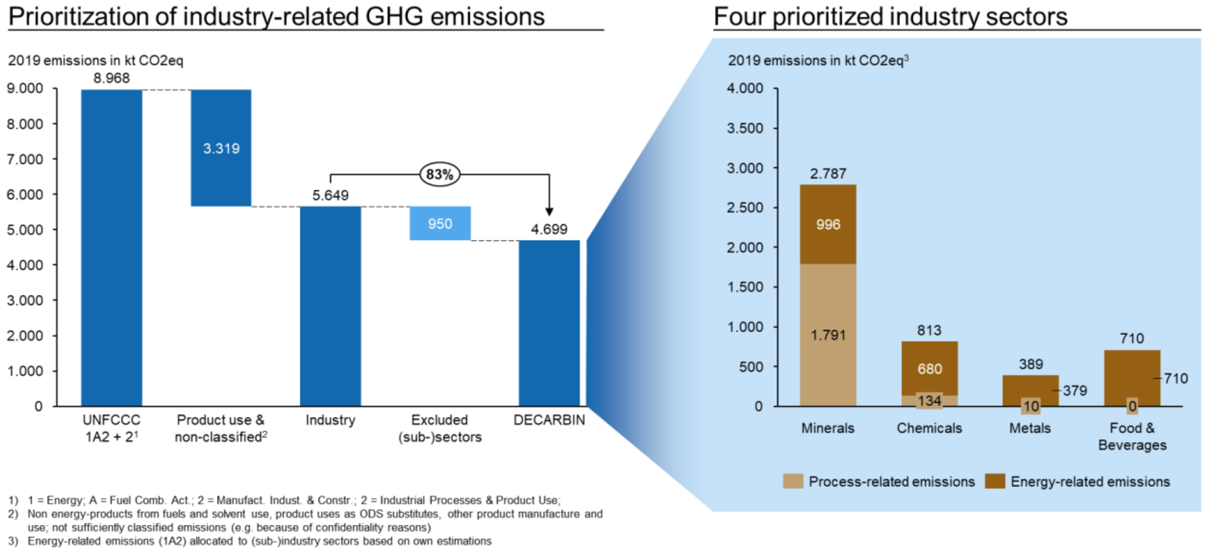

Figure 3 Prioritization of industry-related GHG emissions

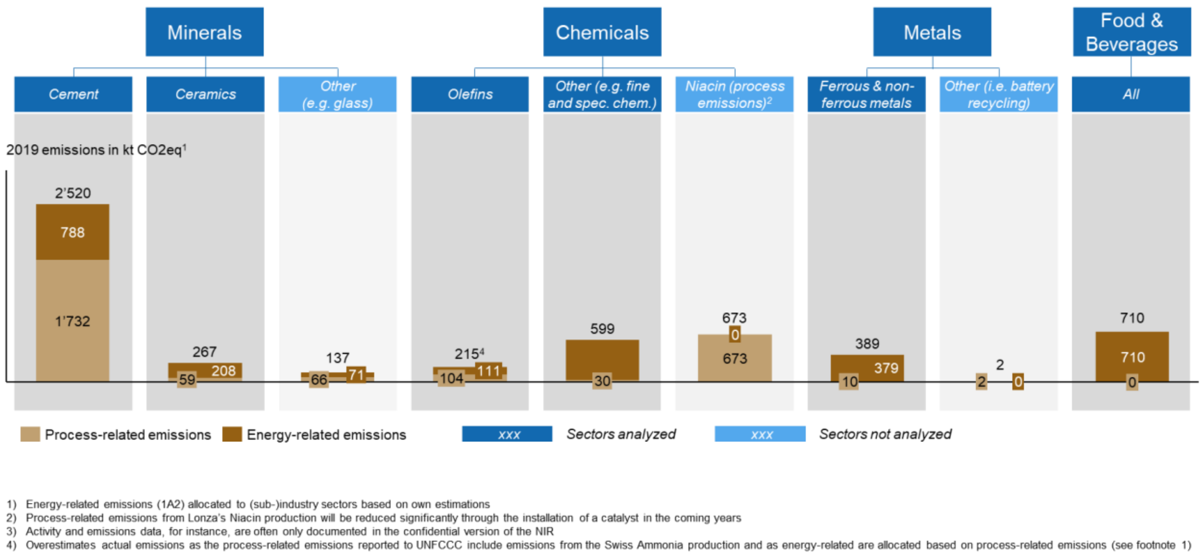

Figure 4 Breakdown of industry-related GHG emissions by sub-sector

Second, by conducting a review of existing studies on industry decarbonization options and results of recent and ongoing projects in European countries (Agora Energiewende, 2019; BMWi, 2020; PBL Netherlands Environmental Assessment Agency, 2021), we created a synthesis of available abatement options for the decarbonization of the prioritized subsectors. As illustrated in the DECARBIN framework in Figure 5, we focused on technological options beyond those typically covered in energy system analysis, namely: (1) Increase of process/system efficiencies, (2) shift towards electricity-based processes (electrification), (3) shift towards alternative fuels, (4) carbon capture and storage (CCS) or use (CCU), and (5) shift to alternative non-energy inputs. Breaking down each of these five options further by differentiating underlying technical approaches gave us a list of available sub-options (Figure 6).

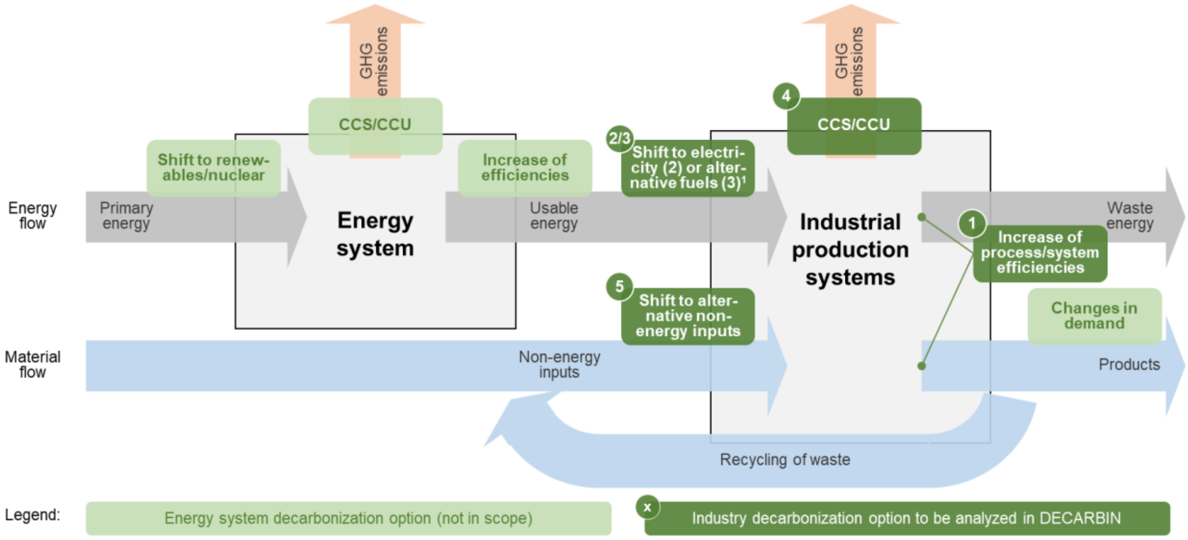

Figure 5 DECARBIN framework illustrating abatement options for the industrial production system

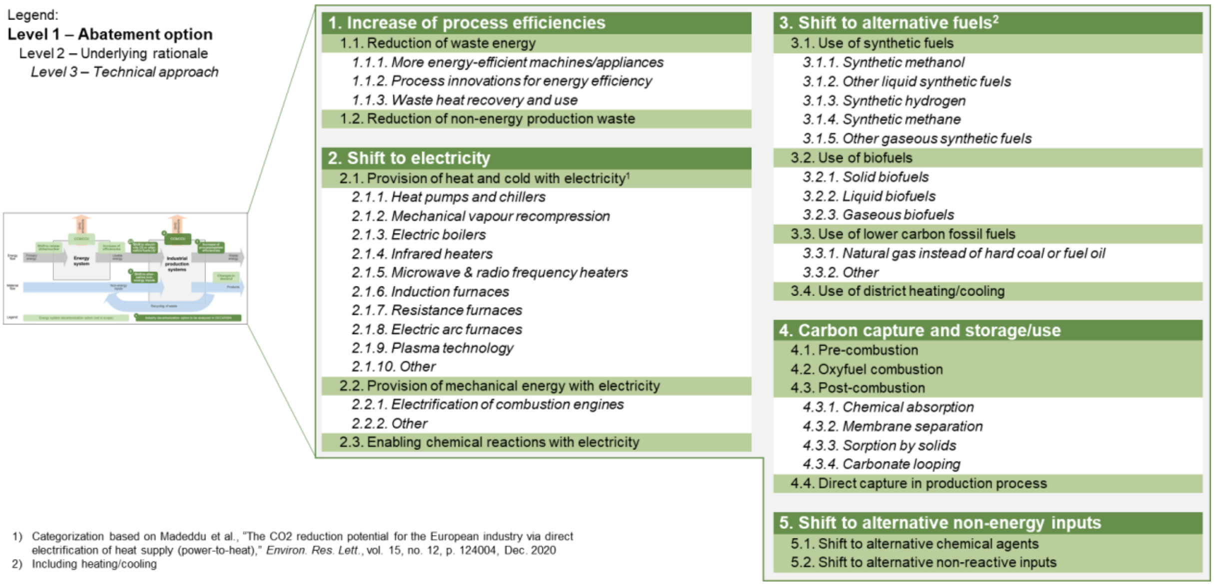

Figure 6 Detailed list of technical approaches structured along the five identified abatement options

Per prioritized industry sector, we then evaluated each of the identified sub-options regarding their specific decarbonization potential, technology readiness, and the prospects for large-scale deployment by 2050 on a scale from 1 to 3 (cf. Figure 7). Based on the three scores and a defined procedure, the sub-options were then given an overall score indicating the relevance of a sub-option for a sector. Figure 8 shows this relevance score aggregated for the five abatement options per industry sector. One can see clearly how the relevance of the five options differs for the prioritized industry sectors. The detailed sector-technology matrix including the full assessment of each technical approach will be published separately from this report.

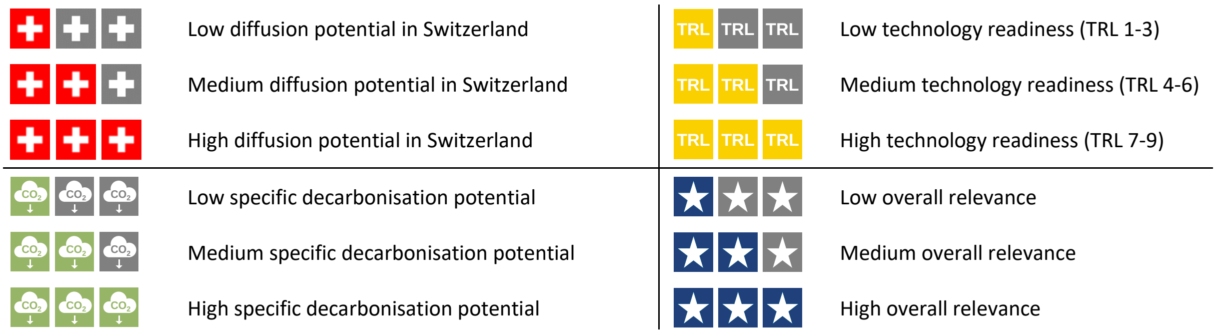

Figure 7 Overview of the scores assigned to each sector-abatement option combination in the developed matrix

	Minerals – Cement	Minerals – Ceramics	Chemicals – Olefins	Chemicals – Other	Ferrous & non-ferrous metals	Food & Beverages
1. Increase of process/ system efficiencies	★★	★	★★	★★★	★★	★★
2. Shift to electricity	★★	★★	★★★	★★★	★★	★★★
3. Shift to alternative fuels	★★	★★★	★★★	★★★	★★★	★★★
4. Carbon capture and storage/use	★★★	★★	★★	★★	★★	★
5. Shift to alternative non-energy inputs	★★	★★	★★			

Figure 8 High-level sector-technology matrix indicating the importance of each abatement option per industry sector

4 Evaluation of results to date

To ensure a high quality of the research, we have established an accompanying advisory group for the project, which we plan to consult prior to each milestone. As elaborated in chapter 2, the current advisory board consists of Dr. Tom Kober (Paul Scherrer Institut), Prof. Dr. Marco Mazzotti (ETH Zurich), Dr. Michael Pahle (Potsdam Institute for Climate Impact Research) and Prof. Dr. Martin Patel (University of Geneva). In the future, more members could be added to the board, for instance, representatives of important industry actors.

The results to date (i.e. the DECARBIN framework and the sector-technology matrix) were discussed with the DECARBIN advisory board and in review meetings with the SFOE. Feedback from the discussions and in written form were incorporated. Furthermore, we plan to conduct expert interviews with relevant industry stakeholders in Switzerland to discuss findings in WPs 1 and 2. The primary mode of interaction will be expert interviews, though we will consider smaller workshops where appropriate.

5 Next steps

As part of WP 2 we will analyse how energy and climate policy can affect the abatement costs of selected options identified in WP 1 and how therefore policy has an influence on investment decisions in selected industry sectors. Although not all relevant industry sectors might be analysed in detail, results will be generalized to the extent possible, and applied to the remaining sectors as appropriate.

The analysed decarbonization options have different cost structures. For instance, the total cost of a solution based on electrifying industry processes (technology option 2) is largely determined by the electricity cost. Here, we aim to uncover the sensitivities of the options' abatement costs towards changes in input costs. These input costs relate to secondary energy in different energy carriers, which in turn are strongly affected by energy and climate policy. Yet, they also relate to other energy/climate policy-affected cost positions, such as investment costs (which may be lowered by grants), or financing cost, which may be lowered by de-risking instruments (e.g., guarantees from the Swiss Technology Fund). To uncover these sensitivities, we build a bottom-up techno-economic model calculating the abatement cost for selected industry sectors. Input parameters will be sourced from literature and in interviews with technology and industry experts. Sensitivities of input parameters will be linked qualitatively to energy/climate policy options.

Based on this assessment of abatement costs, we will analyse how energy and climate policy influences investment decisions into different abatement options. Here we are particularly interested in the influence of policy timing, policy uncertainty, and how different sector characteristics influence the effectiveness and efficiency of the analysed policies.

In WP 3 we will estimate the impact of realistic policy mixes (consisting of energy policies, general climate policies, and potentially industry-specific decarbonization policies) on the Swiss energy system. Given the multiple market failures related to the energy transition (pollution externalities, innovation and learning externalities, carbon leakage, etc.), reaching net zero in 2050 will require a policy mix, potentially adding industry-specific instruments to the current climate/energy policy regime. Table 1 describes instruments to be analysed, based on the economic literature and considerations in various countries.

Table 1 Policy options for industry decarbonization

Policy options	Exemplary policy instruments
A. Carbon pricing	• Carbon taxes • Emissions trading system (cap-and-trade) • Carbon contracts for differences
B. Incentives for technology deployment	• Research and development support • Investment subsidies (e.g., grants) • Instrument to lower financing cost (e.g. loan guarantees)
C. Instrument enhancing international competitiveness	• Linking of emissions trading systems • Carbon border tax adjustments • Other compensation instruments

To assess realistic (as compared to idealised) policy mixes, in DECARBIN we will first derive policy mix scenarios for the Swiss context. To this end, we will collaborate with Prof Edenhofer's group for Climate and Energy Policy at the Potsdam Institute for Climate Impact Research (PIK) in Germany, who recently conducted a major study comparing options to complement existing energy policies with further measures for decarbonization in other sectors, and specifically the role of carbon pricing therein

(Edenhofer et al., 2019). In addition, we plan to involve SFOE representatives early on in this process, for instance, in a joint workshop with PIK in Q1, 2022. Second, we will apply the techno-economic model developed in WP 2 to assess how different policy mixes affect the competitiveness of selected decarbonization technologies identified in WP 1.

Finally, results will allow us to estimate the impact of potential policy mixes (which can have very different outcomes for the objective of decarbonization, such as electrification vs. CCS) on key variables of the Swiss energy sector, such as the demand for electricity, natural gas, and alternative fuels like hydrogen. In this context, we also plan to address non-scope 1 emissions (in contrast to WP 1), e.g. when analysing carbon border tax adjustments for imports of different synthetic fuels. We will qualitatively discuss implications of the secondary energy demand changes for the Swiss energy infrastructure; our quantitative results can also serve as input for subsequent energy system model-based analyses.

6 National and international cooperation

As indicated in chapter 5 for WP 3, we will collaborate with Prof. Edenhofer's group at PIK in Potsdam. The PIK group has started a project on industry decarbonization focussing on Germany and the EU. Specifically, we plan to regularly meet in order to discuss approaches, jointly develop policy portfolio scenarios, and act as respective "challengers" for the modelling to be conducted independently by each group.

For additional oversight, we have also established an advisory board as described in chapter 4. Collaborations with members of the advisory board and their respective teams are conceivable and would help leverage existing research.

Generally, our teams are well-connected with the Swiss energy research community (e.g., as part of the SWEET EDGE program), with established contacts to colleagues working on related topics. In the field of CCS, specifically, we plan to collaborate with the SFOE-funded DemoUpCARMA project to incorporate latest insights on CCS in the DECARBIN modelling (Prof Schmidt and Prof Steffen are part of the consortium). Where available we will also draw on results from industry specific research projects, as for instance the DecarbCem project for the cement industry conducted at ETH. In addition to collaborations with other researchers, we plan to collaborate with companies from Swiss industrial ecosystem, e.g. when it comes to realistic modelling of cost structures and investment decisions.

7 Communication

No communication as of to date.

8 Publications

No publications as of to date.

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