Rollout of carbon capture, transport, and storage infrastructure for hard-to-abate industry in Switzerland

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Abstract

Climate change mitigation requires a dramatic reduction of greenhouse gas emissions across all sectors, including hard-to-abate industries. Hard-to-abate emissions from industry can be avoided by CO2 capture, transport, and storage (CCTS), where CO2 is transported from capture plants to permanent storage sites. However, no CCTS infrastructure is currently deployed in Europe. Therefore, the transition towards a large-scale CCTS infrastructure needs to be properly planned and implemented. Within this context, external factors play a role in the deployment of CCTS supply chains and lead to large uncertainty due to little operational experience for such systems. Here, we investigate the rollout of a Swiss CCTS infrastructure to achieve a net-zero emissions Swiss industry and connect Swiss emitters to a European CCTS infrastructure. We address uncertainty and real-world constraints regarding the rollout of CCTS infrastructure via scenario analysis. Under most scenarios, Swiss CO2 sequestration targets can be reached, although costs may increase by up to 25%. The delay or limitation of available storage capacity, however, can undermine the sequestration targets.

**Keywords**: Carbon capture and storage, CO2 supply chains, hard-to-abate industries, net-zero emissions, CO2 infrastructure, decarbonization.

Introduction

Strategies to reach national and international climate targets not only demand drastic reductions in greenhouse gas emissions (IPCC, 2022) but also increasingly include carbon capture and storage, as well as carbon dioxide removal for reaching net-zero emission goals (Bundesamt für Energie, 2021). Capturing and storing CO2 is a viable option to reduce hard-to-abate emissions in the industrial sector, such as cement or waste incineration plants (Paltsev, 2021). However, no infrastructure for CO2 capture, transport, and storage (CCTS) currently exists in Europe. The transition towards the scale of CCTS required for net-zero emission targets requires fast deployment of large infrastructure systems (IRENA, 2021). This study investigates the cost-optimal rollout of a CCTS supply chain network for Switzerland connected to European CCTS transport routes.

Methods

A linear programming model determines the time-dependent installation and operation of the CCTS infrastructure for Switzerland. More specifically, the optimization model returns the type, location, and size of CO2 capture, conditioning, and transport technologies, as well as the locations for permanent storage. Furthermore, the input and output streams of technologies, including the CO2 flow for the installed transport connections are determined. The model minimizes the total annualized costs of the system while complying with annual CO2 emissions targets and real-world constraints resulting from limitations due to political, societal, or implementation externalities.

The input data to the optimization problem are: (i) current locations and CO2 emissions of Swiss emitters, (ii) location and capacity of CO2 storage sites, (iii) efficiency, CO2 footprint, and investment and operating costs of capture, storage, and transport technologies, (iv) availability of transport technologies between nodes, (v) price and region-specific carbon-intensity of electricity, and (vi) emissions reduction targets for industrial CO2 emissions. As Switzerland has no large-scale domestic storage and no direct access to the sea, it will require exporting CO2 through its neighboring countries. In the model, export takes place in Basel where the Swiss infrastructure is assumed to be connected to a European transport route going towards the North Sea. The input data used in the optimization is based on Becattini et al. (2022) and Gabrielli et al. (2022). The constraints of the optimization problem include (i) energy and mass balances, (ii) performance behavior and operating limits of the capture, conditioning, and transport technologies, and (iii) CO2 emissions limits.

In addition to techno-economic constraints, we include real-world constraints. Although real-world constraints are often neglected, they have a large influence on the deployment speed or even lead to the cancellation of projects (Russel and Bleiker, 2015). The real-world constraints are included as inputs and represent the expectation of how fast a CCTS infrastructure within Switzerland and abroad may develop. The limitations are based on public statements of stakeholders as well as communication with the industry. As the real-world constraints are uncertain, a scenario analysis is used to assess their effect on the Swiss CCTS infrastructure rollout.

The optimization is carried out for the time horizon from 2025 to 2050 and uses a yearly time resolution. We perform a scenario analysis, to investigate the variability in the speed of infrastructure rollout and its effect on the CCTS system. A reference scenario is defined which represents the expected future availability of capture, transport, and storage technologies and their capacities. The reference scenario is the midpoint in the range determined for the real-world constraints. From the reference scenario, additional scenarios are derived which differ in the years when CO2 capture units, pipelines, or storage sites become available. Furthermore, several unfavorable external conditions are analyzed, namely the lack of foreign pipelines for Swiss emitters to connect to, limited navigability of the Rhine River, unavailability of domestic storage, and an unforeseen shutdown of the closest foreign storage sites.

The cost-optimal infrastructure designs are compared for all scenarios to identify (i) robust design decisions taken across a variety of scenarios and (ii) critical parameters jeopardizing the CCTS rollout.

Results

We identify feasible CCTS network designs for 10 out of the 11 analyzed scenarios with a total cost range of ±25% compared to the reference scenario. The biggest cost reductions result from the earlier availability of storage capacity. Compared to the reference scenario, earlier storage availability enables shorter overall transport distances because more storage capacity exists close to Switzerland. Additionally, in this scenario, the Swiss storage site is assumed to become available earlier than in the reference scenario. Significant cost savings are realized when a considerable share of the total CO2 can be stored domestically.

The second largest cost savings are achieved if pipelines can be installed earlier than in the reference scenario. Pipelines are the best mode of transport in an environmental and economic sense (Becattini et al., 2022; Gabrielli et al., 2022). Installing them early reduces the costs and emissions of the CCTS infrastructure, leading to a more efficient and smaller CCTS system to achieve the same CO2 sequestration targets. The time when pipelines become available is thus a large driver for cost savings. The planning and construction of large pipelines are complex and require coordination among different stakeholders. The process must be initiated immediately to realize potential cost savings.

The only case where the optimization does not produce a feasible result is the scenario where storage site development is delayed, and the storage capacity is limited to a maximum of 5.8 MtCO2/y compared to 14.3 MtCO2/y in the reference scenario. The availability of CO2 storage, both in time and capacity, has the largest effect on the results. On the one hand, early availability of storage capacity enables cost reductions in the long term. On the other hand, failure to secure access to CO2 storage may cause Switzerland to overshoot its long-term decarbonization targets. As CO2 storage projects are continuously being announced and developed further (Global CCS Institute, 2022), the availability of storage capacity may depend more on long-term contracts with storage providers and less on the overall availability of injection capacity.

Out of the analyzed parameters, the availability of storage capacity bears the greatest cost-saving opportunity but also the greatest risk for jeopardizing a successful CCTS rollout. Therefore, a Swiss CCTS system designed to meet federal sequestration targets (Bundesamt für Energie BFE, 2021) must ensure the availability of storage capacity. Furthermore, coordinated efforts to construct a pipeline infrastructure must be initiated to enable timely availability of cost- and emission-optimal CO2 transport.

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