Techno-economics of CO₂ capture in industrialized regions with carbon-neutral heat and power generation—A case study of Sweden

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Abstract

Sweden is a heavily industrialized region that has electricity and heating sectors with near-zero carbon emissions. The long-term climate goal set by the Swedish Government is that Sweden should be climate-neutral by Year 2045, i.e., that net emissions from Swedish sources should be zero. Large Swedish point sources of fossil CO₂ emissions include oil refineries, integrated steel mills, cement and chemical production plants. However, the majority of the large point sources of CO₂ are pulp and integrated pulp and paper mills, with their emissions being primarily of biogenic origin. Due to the magnitude of emissions from the pulp and paper industry, there is significant potential for negative emissions by means of BECCS.

This work assesses the investment cost and CO₂ reduction potential of carbon capture from the Swedish process industry. The capital cost for CO₂ capture is estimated for a standard MEA-based CO₂ absorption process. The CO₂ absorption process is applied to key industries—pulp and paper, oil and gas, steel, cement and chemical production—using process modelling for design and cost estimates. The capital cost (CAPEX) is subsequently estimated using a detailed individual factor estimation method. The treated volume flow of gases and the flue gas CO₂ concentration are important factors in determining the cost of CO₂ capture. For a given volume flow, the higher the CO₂ concentration the higher the investment cost, owing to the increased flows of liquid solvent and captured CO₂. Operating expenditures (OPEX), which are dominated by the cost of heat supply for solvent regeneration, but also include other utilities, maintenance, and labour, are evaluated with the assumption that all utilities are delivered by external systems. Waste heat utilization is estimated based on the type of industry, but not considering for individual industrial plants. This approach is used to exemplify the effects of OPEX on the total CO₂ capture cost and its sensitivity to economic assumptions. Costs for transport and storage are taken from literature for conditions relevant for storage near Sweden and added to the capture cost in order to obtain estimates of the total CCS cost.

Figure 1 gives the cumulative investment as a function of the system capacity for annual reduction in CO₂ through CCS, including both CO₂ capture and transport. The sources are sorted in ascending order of specific CAPEX. A considerable reduction in CO₂ emissions can be achieved by targeting the large point sources that have a specific CAPEX <20 €/tCO₂, around 12.5 MtCO₂/a, at a cumulative investment cost for capture of roughly 2,000 M€, or an average specific CAPEX of 17 €/tCO₂. Swedish steel mills, cement plants, and the recovery boilers of large pulp mills are shown to offer low, specific investment costs (10–20 €/tCO₂). Furthermore, considering the significant levels of biomass-related emissions that emanate from the relatively numerous large pulp mills in Sweden, there is significant potential for implementing BECCS. The potential for achieving negative CO₂ emissions from the recovery boilers of the pulp mills included in this study amounts to 13.6 MtCO₂/a.
for a total investment of 2,600 M€. For comparison, Sweden’s total fossil-based CO₂ emissions in Year 2016 (including transport) were estimated to be 53.6 MtCO₂ equivalent/a, of which the total fossil-based emissions from the industrial and heat & power sector amounted to 19.3 MtCO₂. Nevertheless, the strongest influence on the total capture cost is exerted by the cost of steam (>20 €/tCO₂), which underlines the importance of a cost-effective heat supply. The total cost for applying CCS, including transport and storage, to the fossil and biogenic industries included in the study range from 80 to 160 €/tCO₂.

Figure 1. Cumulative investment for CO₂ capture (in M€) as a function of the system capacity for annual reduction in CO₂ emissions through CCS, and the cumulative CAPEX for a ship transport infrastructure in the Nordic region.