***Bio-energy with carbon capture and storage deployment in Sweden: Infrastructure, costs and break-even prices***

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## Overview

The combination of Carbon Capture and Storage (CCS) technologies with energy production from biomass – so-called BECCS – is a promising mitigation technology to remove CO2 from the atmosphere. BECCS is thus recurrently presented as a critically needed technology in long-term scenarios[[1]](#footnote-1). These scenarios assume a significant and fast increase in BECCS capacities over the coming decennias, with a median of 250 MtCO2 yearly additional BECCS capacity between 2030 and 2050 (Nemet et al., 2018). However, the current uptake of BECCS- and CCS uptake more globally - is slower than anticipated. It is thus of highest importance to understand the economic conditions and policies necessary for a rapid up-scaling of BECCS and CCS deployment.

In this paper, we examine the economics of BECCS/CCS deployment in Sweden, a country that provides a relevant and topical case study because of both its large biomass-fuelled pulp and paper sector and the proximity of the storage site currently developed in Norway (Kjärstad et al., 2016; Garðarsdóttir et al., 2018). Moreover, a few large projects are currently under scrutiny to equip Swedish refineries with CCS capabilities. A question of some policy relevance is therefore whether these pioneering projects could serve for a widespread deployment of BECCS.

We propose a novel representation of the coordination problem faced by an heterogeneous collection of industrial emitters that can be connected to a common BECCS/CCS supply chain, including a CCS pilot refinery and a group of neighbouring pulp and paper facilities. Our approach is based on the application of a cooperative game theoretic framework.

Our analysis first highlights that sustainable and incentive-compatible cooperation schemes can be implemented in the Swedish case. We then address the crucial issue that consists in determining the minimum CO2 price needed to verify the conditions for the participation of all the emitters. Lastly, we discuss the implications regarding the industrial organization and regulation of that supply chain. Overall, we believe that this analysis usefully contributes to the current policy discussions regarding the institutional framework needed for negative emission technologies in Sweden.

## Methods

We develop a cooperative game theoretic approach to examine the coordination issues faced by the considered collection of independent agents (Massol et al., 2015). The break-even CO2 value for joint CCS adoption is thereby defined as the minimum value of the prevailing carbon price that is compatible with the construction of the projected infrastructure. Specifically, we test the different configurations among emitters by evaluating what cost is collectively incurred by any subgroup of players. We then identify whether there exists a break-even CO2 price and a cost distribution vector such that (i) no subgroup of players has an incentive to disband and (ii) all facilities get a non-negative net benefit from their adoption of CCS/BECCS.

## Results

As an application, we examine the deployment of a mixed pipeline and shipping infrastructure connecting seven large industrial emitters (i.e. emitting more than 500 ktCO2/a) to a Norwegian storage site. Among these seven emitters, one refinery is currently a CCS pilot, and four are pulp and paper facilities that could provide BECCS.

Our findings first confirms the possibility to share the cost of that infrastructure in an incentive-compatible manner and indicate that 120€/tCO2 is a valid break-even CO2 price. From a regulatory perspective, our results also show that this break-even price is little affected by the industrial organization retained for the various components of the supply chain. Indeed, the same break-even price is obtained under a single integrated operator controlling both the pipeline and the vessels and under two independent dedicated firms (i.e., a pipeline operator and shipping one). Finally, that a differentiated CO2 pricing between fossil CCS and bio-CCS does not significantly our results.

## Conclusions

The question of how to organize the construction of a large scale CO2 transport and storage system is an essential issue that policymakers should address to support a rapid up-scaling of Bio-Energy wih Carbon Capture and Carbon Capture and Storage in general. Accounting for the coordination of actors along the value chain is critical for identifying the viable and mutually agreed cooperation scheme at a regional level that is needed for accelerating the adoption of CCS.

This paper build upon a topical case study to clarify the conditions that enable the construction of a joint BECCS and CCS transport infrastructure. We find that a sustainable and incentive-cooperation scheme can be implemented in the considered Swedish region, assuming a discriminatory CO2 transport pricing and a high-enough CO2 value.

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1. For example, of all scenarios associated with a high (i.e. 66%) likelihood of achieving the 2°C goal, 87% include large-scale BECCS deployment (Fuss et al., 2014). [↑](#footnote-ref-1)