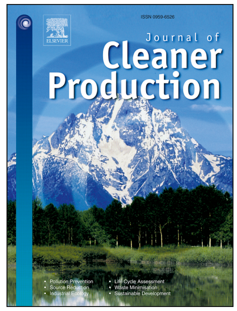
Journal Pre-proof



Tensions in the energy transition: Swedish and Finnish company perspectives on bioenergy with carbon capture and storage

Emily Rodriguez, Adrian Lefvert, Mathias Fridahl, Stefan Grönkvist, Simon Haikola, Anders Hansson

PII: S0959-6526(20)34571-6

DOI: https://doi.org/10.1016/j.jclepro.2020.124527

Reference: JCLP 124527

To appear in: *Journal of Cleaner Production*

Received Date: 26 May 2020

Revised Date: 23 September 2020

Accepted Date: 3 October 2020

Please cite this article as: Rodriguez E, Lefvert A, Fridahl M, Grönkvist S, Haikola S, Hansson A, Tensions in the energy transition: Swedish and Finnish company perspectives on bioenergy with carbon capture and storage, *Journal of Cleaner Production*, https://doi.org/10.1016/j.jclepro.2020.124527.

1. Introduction

Bioenergy with carbon capture and storage (BECCS) is increasingly seen as a key, but contested, technology in mitigating climate change (IEA, 2018; Rogelj *et al.*, 2018). In theory, BECCS could help enable a carbon sink from the atmosphere (Azar *et al.*, 2010; Haszeldine *et al.*, 2018). Negative carbon dioxide (CO_2) emissions can arise when the amount of carbon that is captured by the system is higher than the amount that is released, and as such certain technologies can be framed as net negative. However, assuming large-scale implementation of BECCS has been heavily criticized, in part because there has not yet been any large-scale demonstration of the entire chain of technologies, i.e. capture, transportation and storage (e.g. Beck and Mahony, 2018; Livingston, 2018). As a result, BECCS and other possible negative emission technologies (NETs) have been argued to give false hope for the future and contribute further to the fossil carbon lock-in (Anderson and Peters, 2016). Furthermore, the amount of BECCS needed in some of the global scenarios developed using integrated assessment models (IAMs) has raised concern on the availability of biomass, and the potential trade-offs with food security and biodiversity that would come with it (Fuss *et al.*, 2018; Smith *et al.*, 2015). Conversely, these concerns are not explicit for BECCS in a European context (Darda *et al.*, 2019). Yet, while emissions continue to rise, these concerns seem to take a backseat as the public debate on BECCS has moved towards a reluctant acceptance of this technology (Haikola *et al.*, 2019). Consequently, many researchers continue to see BECCS and other possible NETs as necessary to balance the carbon budget (Nemet *et al.*, 2018; van Vuuren *et al.*, 2017).

Finland and Sweden have potential to implement BECCS due to a high share of biogenic CO_2 emissions at large point sources such as pulp and paper mills and district heating plants

(Onarheim *et al.*, 2017b; Rydén *et al.*, 2017). According to the European Pollutant Release and Transfer Register (E-PRTR), in 2017, Finland and Sweden reported 51% and 64% biogenic emissions, respectively, in facilities emitting more than 100 kt of CO_2. In comparison, the 31 European states in the register (including Finland and Sweden) together reported 6% biogenic CO_2 emissions (EEA, 2019). As such, there is an opportunity for Finland and Sweden to create net negative emissions, which could contribute to sustainability efforts in both countries. The total CO_2 emissions in Finland and Sweden in 2018 were 45.9 Mt and 41.8 Mt respectively[1] (Official Statistics of Finland, 2018; Official Statistics of Sweden, 2019). Furthermore, other GHG that are evaluated in CO_2 equivalents, such as methane (CH_4), amounted to 10.5 Mt in Finland and 10.0 Mt in Sweden. In comparison, Garðarsdóttir *et al.* (2018) has estimated the potential for capturing biogenic emissions from the recovery boiler of selected Swedish pulp and paper mills (>0.5 Mt CO_2 yr^{-1}) to 13.6 Mt CO_2 yr^{-1}; some of the companies with large point sources of emissions operate in both Finland and Sweden. These companies are committed to sustainability and contributing to the Sustainable Development Goals through their sustainability strategies, including climate action; responsible consumption and production; affordable and clean energy; and industry, innovation and infrastructure. In addition, both countries have ambitious climate goals of achieving net zero greenhouse gas (GHG) emissions by 2035 and

[1] The data cover total emissions in 2018, excluding land use, land use change and forestry (LULUCF) as well as biogenic CO_2 emissions from fuels. LULUCF act as a big sink in both countries.

2045 respectively[2] (UN, 2017; UN, 2019). These trends, overlap in key actors, proximity, and similar conditions, mean that Finland and Sweden could potentially share knowledge as well as CO_2 transportation infrastructure, such as to CO_2 storage facilities in neighbouring Norway. Within this regional context, the energy utility company Stockholm Exergi launched a pilot BECCS project in 2019, and the energy company Equinor in Norway has an ongoing investigation into new storage facilities for imported CO_2 (SOU, 2020:4).

The research on the potential for BECCS, however, persistently takes a top-down approach (Hansson *et al.*, 2020). BECCS is context dependent, and tensions in the debate include concerns about feasibility, costs, risks, responsibilities and trade-offs (Cox *et al.*, 2018; Fuss *et al.*, 2018). Surprisingly few studies have approached the issue bottom-up, i.e. by exploring the perspectives of key actors that could potentially implement carbon capture (Braunreiter and Bennett, 2017). This corresponds to a gap in the current knowledge, since asking key companies about their views on BECCS is important to realise or assess practical strategies to reach national climate goals (Geden and Schenuit, 2019). Companies' views could add knowledge in discussions regarding multiple dimensions on BECCS from application of carbon capture technology to policy preferences that could contribute to cleaner production. In addition, company stakeholders' views on BECCS could contribute to a dialogue among key actors to understand contextual factors and to build trust (Nisbet, 2019).

[2] Note that what can be accounted for to fulfil the two goals differ between the countries, which complicates comparisons of target years without understanding the underpinning metrics.

Within a Swedish and Finnish context, companies have only recently started to discuss and consider BECCS which is not implemented on a large scale. It is too early to conduct a technoeconomic analysis since reliable quantitative data is largely unavailable for this region. As such, this study considers bottom-up perspectives from industries, and by doing that, it is the first qualitative study of its kind which seeks to highlight company actors' perspectives on BECCS within a Nordic regional context and to explore their perspectives on emerging tensions in the energy transition. Through interviews with large-scale emitters of biogenic CO_2 in Finland and Sweden, this study addresses the following research questions: What are the barriers and driving forces to realise BECCS according to company representatives, including their views on policy and technical aspects? What do these stakeholders foresee as their company's role in contributing to national climate goals, and how does BECCS fit into climate change measures in company strategies?

2. Background

CCS is a powerful climate change mitigation tool, but it is difficult to find company strategies about carbon capture (Wennersten *et al.*, 2015). This could be because taking decisions about carbon management, such as investing in carbon capture at industrial facilities, is a multifaceted challenge for companies requiring a structured decision-making approach (Campbell-Árvai *et al.*, 2019) Decision-making processes regarding investments, such as in BECCS, could approach energy management on both operational and strategic levels (Rasmussen, 2020) This means that investing in BECCS includes considering industrial processes and how it factors into a company's broader strategy. Furthermore, through interviews with companies involved in the upstream extraction and the downstream handling of fossil fuels, Braunreiter and Bennett (2017) show that incorporating carbon capture and storage (CCS) into processes within those industries would require business strategy changes.

In business models of CCS projects, the factors contributing to their success include regulatory frameworks, infrastructure, permitting processes and public acceptance (Kapetaki and Scowcroft, 2017; Kefford *et al.*, 2018). This emphasis on the agency of policies is evident; even though upstream and downstream oil and gas companies are investing in CCS development, they are not willing to invest in commercial scale CCS without the possibility to receive payback for taking the financial risk (Braunreiter and Bennett, 2017). At the same time, these companies are often positive to CCS as an economical solution to maintain the status quo without considering other alternative futures (Gunderson *et al.*, 2020).

2.2 Political context for BECCS in Sweden and Finland

The energy transition in Sweden and Finland has been driven by policy instruments, energy security and business opportunity (Sovacool, 2017). A carbon tax was introduced in Sweden in 1991 (SEA, 2006), and a landfill tax including a ban on combustible waste in landfills began in 2000 (Swedish EPA, 2005). In 2003, a green electricity certificate system was put in place in Sweden, rewarding producers of renewable electricity with certificates that could be sold on a market based on a quota for the electricity suppliers (SEA, 2020b). Similarly, Finland introduced a carbon tax in 1990, however, most industries were soon after exempted from this tax (Gronow and Ylä□Anttila, 2019). Moreover, organic waste has been banned from landfills in Finland since 2016 (EEA, 2013), and municipal waste has increasingly been used for district heating, with about 1% of waste ending up in landfills annually (Official Statistics of Finland, 2018). In addition to these policy instruments, synergies for biomass usage have developed in both countries between the forestry and district heating sectors (Ericsson *et al.*, 2004), where residue from the forest industry can be used either as fuel for industry processes and/or district heating for nearby municipalities (Werner, 2017). The 1970s oil crisis has also played a role in the energy transition. Even though this energy transition is supported by policies, culture and business strategies, there is a gap in how companies prioritise energy management in their strategies (Thollander and Ottosson, 2010).

A new climate framework was adopted in Sweden in 2017 (Lövin and Wallström, 2017). Subsequently, in January 2020, an inquiry on behalf of the Swedish government published a pathway to reaching the negative emissions outlined by the climate framework, including political suggestions to realise deployment of BECCS (SOU, 2020:4). In Finland, the government's climate change plan emphasizes reducing GHG emissions while strengthening carbon sinks and accounting for the full land use, land-use change and forestry (LULUCF) sink to meet its climate target; Finland's national strategy does not include BECCS (Ministry of the Environment in Finland, 2017). In contrast, Sweden does not allow this use of natural carbon sinks to meet its climate targets, so Sweden is counting on BECCS to deliver 1.8 Mt CO_2 yr^{-1} negative emissions, starting in 2030 (SOU, 2020:4). Furthermore, BECCS is already listed as a climate change measure in the Declaration on Nordic Carbon Neutrality (Nordic Council of Ministers, 2019). Meanwhile, Fauré *et al.* (2019) developed four scenarios for Sweden to comply with the 1.5°C target in 2050 which did not rely on NETs. Instead, the scenarios required significant changes in lifestyle and consumption patterns (Fauré *et al.*, 2019).

Another relevant regional instrument is the EU Emissions Trading Scheme (ETS), a cap and trade system where companies have a decreasing amount of emissions allowances over time (EC, 2020). But in its current state, the EU ETS does not provide incentives for BECCS since the CO_2 emissions from biomass are not covered (EC, 2020). Biogenic CO_2 emissions are not registered in a way that would encourage the implementation of BECCS through some of the current policy instruments in Sweden or Finland.

2.3 Industrial context for BECCS in Sweden and Finland

Finland and Sweden have the highest percentage of land covered with forest in Europe; including large-scale industries that utilise this natural resource. In 2018, Finland's export from the forest industry was worth €13.0 billion, including furniture (Finnish Forest Industries, 2020). Meanwhile, Sweden is the third largest exporter of pulp, paper and sawn timber in the world, with an export value of €14.5 billion in 2018 (Swedish Forest Industries, 2020). In 2018, Finland produced 38 TWh of district heating, and wood residue or forest chips made-up 36% of the fuel (Official Statistics of Finland, 2019). Similarly, in Sweden, 56.8 TWh of district heating was produced in 2018, and biomass composed 62% of the fuel (SEA, 2020a).

This tradition of consuming forest resources at large emission point sources has renewed interest in carbon capture in Sweden and Finland. One of the first reports on CCS in the Baltic Sea region was initiated by the Swedish Energy Agency (SEA) (2010) together with academic and industrial actors, finding that CCS infrastructure would require collaborations and policy incentives. Since 2010, techno-economic studies on CCS opportunities focus on the pre-requisites of the Nordic industry (e.g. Onarheim *et al.*, 2015; Rydén *et al.*, 2017) and the possible development of a transportation system (e.g. Kjärstad *et al.*, 2016; Lauri *et al.*, 2014). Similar to the SEA report (2010), transportation of CO_2 to a suitable storage location is a key question in the Nordics; the long distances combined with comparatively small point emission sources (in many cases 0.5-1.0 Mt) make ships seem like a suitable option in combination with storage in Norway. Another alternative to storing CO_2 is to make use of it in a product through carbon capture and utilisation (CCU). Industrial applications of CCU include electrofuels, concrete curing, horticulture production and lignin extraction from black liquor. However, there is often a geographical mismatch between where CO_2 is available and where it could potentially be utilized on a large scale (Patricio *et al.*, 2017a; Patricio *et al.*, 2017b).

Different capture technology options have also been investigated. Garðarsdóttir *et al.* (2018) found that the specific cost of CO_2 capture using monoethanolamine (MEA) depended more on an economy of scale than on the flue gas stream concentration of CO_2. However, other capture technology alternatives exist where the concentration in the flue gas stream has a greater effect on efficiency, e.g. oxyfuel combustion (Grönkvist *et al.*, 2006). Moreover, Bui *et al.* (2018) recently reviewed the development of CCS systems and components. They found that other alternatives such as polymeric membranes, pre-combustion and oxyfuel combustion are increasing their technology readiness level, now only a few steps away from becoming commercially available. In addition, Stockholm Exergi suggested that hot potassium carbonate (HPC) is a suitable option instead of MEA in combined heat and power (CHP) applications (Levihn *et al.*, 2019).

3. Method

An inductive and exploratory approach has been used to investigate Swedish and Finnish companies' perspectives on BECCS, including a top-down mapping and bottom-up interviews with company representatives. The interview questionnaire is provided in supplementary material "Appendix A". The material collected through these interviews has been analysed using a qualitative approach.

3.1 Identifying the largest emitters of biogenic carbon dioxide

The European Environmental Agency (EEA) has publicly available country- and facility-level data on GHG emissions via the European Pollutant Release and Transfer Register (E-PRTR), version 16 (EEA, 2019). The share of biogenic CO_2 is reported voluntarily to E-PRTR, but Sweden and Finland's reported biogenic emissions are consistent with national GHG inventories (Fridahl and Bellamy, 2018). In 2017, Swedish and Finnish biogenic CO_2 emissions at point sources larger than 0.3 Mt, added up to approximately 46 Mt (EEA, 2019). A three-year average of this data (2014–2016) was used to identify the facilities emitting more than 0.3 Mt CO_2 yr^{-1} (EEA, 2019).[3] Fifty-one pulp mills or district heating plants in Sweden and Finland fit the criterion of 0.3 Mt biogenic CO_2 yr^{-1} including 18 facilities with over 1.0 Mt CO_2 yr^{-1}. The largest facility emits approximately 2.0 Mt biogenic CO_2 yr^{-1}.

A map was created in ArcGIS,[4] and these 51 facilities are in turn operated by 24 companies. To maintain confidentiality, each company is referred to by the main business sector of these facilities, either "F" for forest or "E" for energy and assigned a unique number (for example, "E1"), which is used to reference each company in the results (section 4). Note that these

[3] The IPCC Special Report on CCS defines large stationary emission points as above 0.1 Mt CO_2 yr^{-1} (IPCC, 2005). At lower emission levels, the cost for transporting CO_2 would increase (Kjärstad *et al.*, 2016), and even at points around 0.5 Mt CO_2 yr^{-1}, it might be necessary to cluster emissions to increase cost-efficiency (Kjärstad *et al.*, 2016; SEA, 2010).
[4] ArcGIS® software by Esri. ArcGIS® is the intellectual property of Esri and used herein under license.

unnamed company references are merely to show examples and are not intended as a conclusive list of companies that give voice to a specific view. The companies in this study range from district heating plants operated by municipalities to international companies that manage forests and production operations in several countries. The products produced by the companies include pulp, paper, packaging, heat and energy. Although 24 companies were invited to participate in research interviews, a subset of 20 companies took part in this study as listed in Table 1.

Table 1. *The 24 Swedish and Finnish companies with facilities emitting on average >0.3 Mt biogenic* CO_2 yr^{-1} *in the period 2014 to 2016, listed alphabetically.*

Company	**No. of facilities >0.3 Mt CO_2 yr^{-1}**	**Interview date**	**No. of inter-viewees**	**Country**	**Main sector**
Ahlstrom-Munksjö	1	No interview		Sweden	Energy
Alholmens Kraft	1	29/11/2019	1	Finland	Energy
BillerudKorsnäs	5	04/03/2020	1	Sweden	Forest
Domsjö adity	1	No interview		Sweden	Forest
Eskilstuna Energi och Miljö	1	12/05/2020	1	Sweden	Energy
E.On	1	18/10/2019	1	Sweden	Energy
Holmen	1	22/08/2019	1	Sweden	Forest
Metsä Group	5	24/02/2020	2	Sweden & Finland	Forest
Mondi Dynäs	1	30/10/2019	1	Sweden	Forest
Mälarenergi	1	19/08/2019	1	Sweden	Energy
Nordic Paper	1	No interview		Sweden	Forest
Pohjolan Voima Oyj	2	04/05/2020	1	Finland	Energy
Renova	1	No interview		Sweden	Energy
Rottneros	1	04/09/2019	1	Sweden	Forest
SCA	4	30/09/2019	1	Sweden	Forest
Smurfit Kappa	1	21/08/2019	1	Sweden	Forest
Stockholm Exergi	3	12/09/2019 and 11/10/2019	2	Sweden	Energy
Stora Enso	10	11/10/2019	1	Sweden & Finland	Forest
Sysav	1	14/05/2020	2	Sweden	Energy
Söderenergi	1	12/09/2019	1	Sweden	Energy
Södra	3	26/09/2019	2	Sweden	Forest
Tekniska Verken	1	10/01/2020	4	Sweden	Energy
Umeå Energi	1	04/11/2019	1	Sweden	Energy
UPM	3	17/02/2020	1	Finland	Forest

3.2 Semi-structured interviews

The 24 companies listed in Table 1 were contacted via phone and email and invited to participate in the study. Companies were asked to select appropriate representatives for this study based on the interview subject of BECCS, so the companies had the discretion to choose representatives. Interviews were conducted during the period August 2019 to May 2020, with representatives from companies, including employees working at company headquarters, national offices or facility-level. Each interview was recorded and lasted 40 to 75 minutes. One or two researchers participated in each interview together with one to four representatives from each company, including sustainability directors, energy engineers, and R&D managers. A total of 27 company representatives participated in interviews as shown in Table 1.

The interviews followed a semi-structured interview script (see Appendix A), allowing for flexibility regarding the order and number of questions; not all scripted questions were included in each interview (Kvale and Brinkmann, 2009). The nature of the interviews also enabled the inclusion of company-specific questions and follow-up questions. The interviews centred around dialogue which is a collective activity where the researcher and respondent co-create knowledge through interaction (Kvale and Brinkmann, 2009). The dialogue is a tool to understand different viewpoints, such as from industry actors regarding climate change solutions (Nisbet, 2019). Interviews were conducted in Swedish or English and took place via video conference, telephone or face-to-face. Afterwards, the interview audio recordings were transcribed word-for-word. The quotations in the results (section 4) from the interviews conducted in Swedish have been translated.

The interviews were structured around the following topics: national climate goals, NETs and BECCS, the company's sustainability goals, and technical aspects related to energy use and sustainable production.

3.3 Analytical framework

The analysis process was based on an inductive approach where the empirical data collected from interviews formed the foundation of the analysis to identify themes and patterns. Inductive coding was used to cluster the qualitative data to identify patterns and themes (Saldaña, 2013) Four recurring tensions were identified to structure the analysis. First, reliable long-term policies and regulations necessary for an energy transition are currently lacking to implement climate measures such as BECCS. Second, companies do not see themselves as part of the root cause of climate change but as contributors to the solution by merely sustaining their conventional sustainability efforts. Third, the timing of investments and technical factors, such as process integration, that are necessary to implement BECCS on the facility level include trade-offs between site-specific factors at facilities and industry-specific factors. And fourth, customer preferences and demands for net negative carbon emissions, which have not yet surfaced, have a role in influencing companies' decisions regarding investments and sustainability priorities. A summary table has been created to highlight the main results and most frequently occurring patterns in this study based on thematic analysis of the interview transcripts.

3.4 Methodological limitations

This study includes the perspectives of company representatives from industries with the largest point source emissions of biogenic CO_2 in Sweden and Finland. A methodological concern is that responses may be biased based on the participants' knowledge and their individual perspectives, which may not be representative of the company itself. In addition, this could limit the generalizability of the conclusions. Although different viewpoints could have arisen from selecting a set of other interviewees, the aggregated response patterns seem robust. Furthermore, respondents were informed that the Swedish Energy Agency is funding this study, which may have influenced how companies responded, since they may have an interest in portraying certain views. The analytical framework focuses on tensions that emerged during interviews, but different interpretations could be derived from interview transcripts using other analytical framings. Finally, the example of views of companies listed in the results section, including the results table, provide examples, but due to the qualitative nature of the interviews, these examples may be incomplete. Additional companies may share these viewpoints even though they did not express it during the interview. Therefore, the results table is not exhaustive, but it is a tool to highlight the most prevalent patterns from this study.

4. Results

The facilities with the largest amount of biogenic CO_2 emissions in Sweden and Finland are chemical pulp mills in addition to CHP plants for district heating. Figure 1 shows a map of the 51 facilities in Sweden and Finland that emit more than 0.3 Mt biogenic CO_2 yr^{-1} (EEA, 2019).

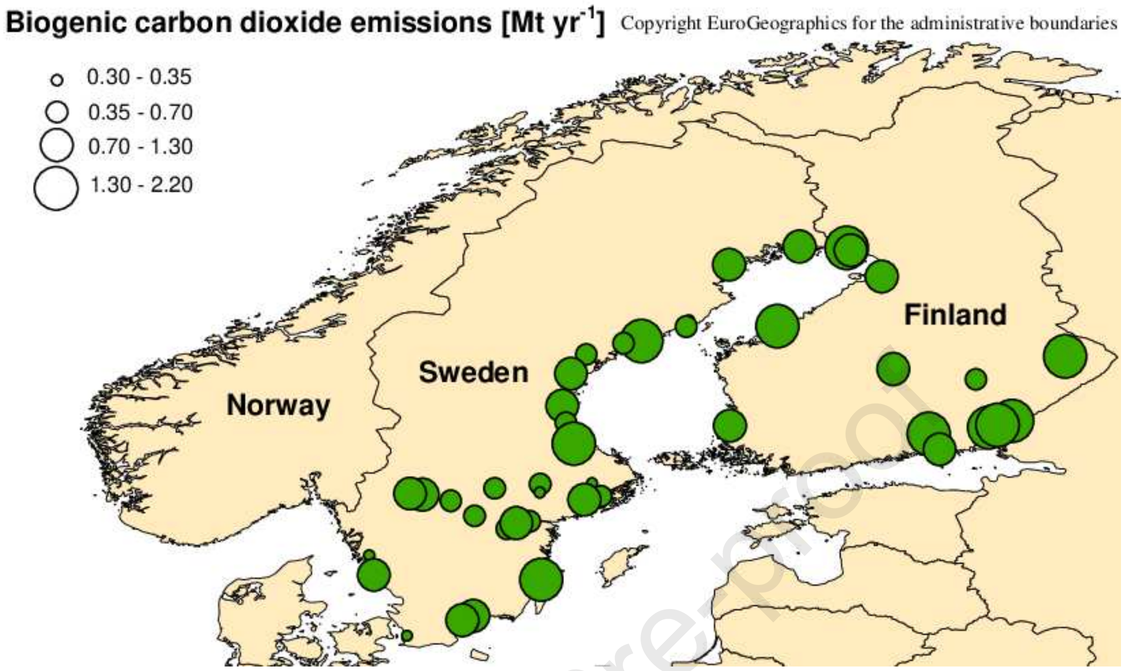


Figure 1. *Map of the facilities emitting on average more than 0.3 Mt biogenic CO_2 yr^{-1} during the period 2014-2016, E-PRTR version 17 (EEA, 2019). Administrative boundaries from EuroGraphics (Eurostat, 2019).*

Although the results of this study are qualitative in nature, a quantification of company perspectives is provided in Table 2 and Table 3. In Table 2, two relevant factors concerning the possible development of BECCS: “Knowledge about carbon capture technology” and “Potential time frame for BECCS going forward”, are presented together with companies’ perspectives. More than half of the companies state that they are keeping up with the news around BECCS, however, about half of the companies are also prioritizing other technologies. Notably, more energy utilities than forest companies expressed that they are considering BECCS in the future, while at the same time, more forest companies stated that they have conducted their own pre-study about BECCS (ranging from informal reports to projects that have received funding from the Swedish Energy Agency). In contrast, a few of the companies discussed CCU as alternative starting points, often talking about the increased profitability of having a product to sell in that case. Only three companies are not currently engaged with the subject. While there is a difference in level of knowledge compared to the companies that are keeping up with the news, it should be noted that companies not currently engaged with BECCS still had some basic understanding of the technology.

Table 2. *Summary of the companies' perspectives considering two factors, knowledge about carbon capture technology and potential time frame for BECCS going forward.*

Main sector	Knowledge about carbon capture technology			
	Not currently engaged	Keeping up to date with news	In-house carbon capture pre-study	Working on a pilot/demo plant
Energy	1	7	1	1
Forest	2	5	3	0

	Potential time frame for BECCS going forward		
	Prioritize technologies other than BECCS	Considers CCU a more realistic starting point	Considers investing in BECCS
Energy	4	2	4
Forest	6	2	1

The companies also expressed many specific perspectives during the interviews which are described in the remainder of the results section. Table 3 presents an overview of the 10 most prevalent perspectives expressed by the companies. For example, a large share of the energy and forest companies expressed that they have a long history of focusing on increasing both efficiency and productivity. Furthermore, many of the companies pointed towards the cost barrier when talking about a potential investment in BECCS. This is linked with the perspective that BECCS necessitates a suitable and profitable business case.

Table 3. *Top 10 most prevalent perspectives on BECCS and sustainability expressed during interviews, listing the viewpoints presented by the largest number of companies.*

Perspective	Energy companies [E*n*]	Forest companies [F*n*]	Section where this perspective is detailed
Have had a long focus on increasing energy efficiency and productivity	1, 2, 3, 5, 6, 7, 8, & 9	3, 4, 5, 6, 7, 9, & 10	*4.3 Technical trade-offs of carbon capture*
The cost barrier for implementing BECCS is significant	1, 3, 5, 6, 7, 8, & 9	1, 4, 5, 9, & 10	*4.1 Absence of reliable long-term policies for BECCS*
BECCS necessitates a suitable and profitable business case	2, 3, 4, 7, 8, & 9	1, 4, 5, 6, 7, & 8	*4.1 Absence of reliable long-term policies for BECCS*
Switching from fossil fuels to renewables	3, 4, 6, 7, 8, 9, & 10	3, 5, 6, & 8	*4.2 Limits to companies' climate change responsibility*
Trade associations as key to collaborate with other companies and government actors	4, 5, & 8	3, 5, 7, 8, 9, & 10	*4.1 Absence of reliable long-term policies for BECCS*
Carbon capture does not pose any specific technoeconomic risk to other parts of the facility	1, 5, 6, 7, 8, & 9	1, 5, & 6	*4.3 Technical trade-offs of carbon capture*
Influence of the EU on the potential for BECCS (EU ETS and other initiatives)	2, 3, 4, & 8	1, 5, 7, & 9	*4.1 Absence of reliable long-term policies for BECCS*
The forestry sector already has net negative GHG emissions	–	2, 5, 6, 7, 8, 9, & 10	*4.2 Limits to companies' climate change responsibility*
Norway is a potential starting point for CO_2 storage	2, 4, 6, 7, 8, & 9	9	*4.3 Technical trade-offs of carbon capture*
Unwilling to be first movers on BECCS	2, 6, &10	3, 4, 5, & 9	*4.3 Technical trade-offs of carbon capture*

4.1 Absence of reliable long-term policies for BECCS

The cost barrier of implementing BECCS was brought up by both the energy utility sector and the forest industry [E1, E3, E5, E6, E7, E8, E9, F1, F4, F5, F9, F10]. For example, one company stated that there is a need for government support for demonstration plants in order to gain more experience with BECCS [E1]. Furthermore, in addition to a lack of reliable long-term policies and current BECCS projects, there is no large-scale market for CO_2 as a product (see section 2.2). A recurring tension according to the company representatives is that investments in novel technologies are weighed against other investments. As one respondent noted:

> *We are investing X per year. We are not going to suddenly increase that to Y per year. This is the investment rate we have, and other investments would not take place* [if we were to invest in BECCS] */…/ There is a problem with making carbon capture artificially very profitable, since then the forest industry would certainly do it, but it would be at the expense of increased productivity which could have an equal or even larger climate benefit.* [F5]

EU-level and national policies influence industries' ability to act on climate change. While carbon capture technology is "not rocket science" [E3], a major question is how the regulatory system should be designed [F1]. Another respondent mentioned that regulatory systems govern what companies can and cannot do, impacting their priorities [E6]. Respondents agree that a suitable and profitable business case would be necessary for BECCS [E2, E3, E4, E7, E8, E9, F1, F4, F5, F6, F7, F8].

Several companies mentioned the influence of the EU on the potential for BECCS, including the EU ETS and other initiatives [E2, E3, E4, E8, F1, F5, F7, F9]. According to one respondent, incorporating BECCS in existing systems such as the EU ETS is important, in addition to finding markets for CO_2 such as in the food industry [E3]. Another company representative stated that there could be opportunity to pursue BECCS via the EU Innovation Fund [E4]. Two companies named Best Available Techniques (BAT)[5] which is included in the EU's Industrial Emissions Directive (EP, 2010), as a driver for sustainability actions within companies [E2, F3]. One respondent stressed the importance of designing a system for emissions trading without loopholes [F5]. For example, a system could be designed, as proposed by one company, where producers that use fossil fuels in their products contribute to a fund that supports CCS [E9]. Another company representative was critical of the EU Renewable Energy Directive (EP, 2009) but suggested a resource directive as an alternative solution, which could enable a more holistic approach to resource flows, such as the carbon cycle, instead of only point source emissions [E3].

Taxes influence companies' strategies and priorities, and consequently also the willingness to consider BECCS. According to one company, a market or policy hybrid, possibly including a certificate system could be a solution for BECCS [E4]. There is currently no tax to incentivize negative emissions, but an idea put forward by some energy utility companies is that there could be a negative CO_2 tax or a credit against a CO_2 tax, so that an emitter of CO_2 would get paid as

[5] BAT refers to environmental protections that guide industries regarding emissions, water, energy, waste and associated monitoring (EC, 2020).

much for capturing CO_2 as they would pay to emit it [E2, E3, E4, E6, E9]. Another company representative's idea is to impose a tax on the polluting industries, for example a "global cement tax," to pay for the costs associated with constructing CCS infrastructure [F5].

Related to political support, nearly all companies in this study referred to trade associations.[6] Companies described trade associations as a key vehicle for collaborating with other companies and government actors [E4, E5, E8, F3, F5, F7, F8, F9, F10]. One company described a coordinated response among trade associations in Sweden and Finland to educate the EU Commission on integrated pulp mills [F10]. In addition, there have been BECCS policy discussions in at least one of the associations [E7].

4.2 Limits to companies' climate change responsibility

According to the company representatives in this study, there is a tension between who and what have caused GHG emissions, and who are leading efforts to reduce GHG emissions. The companies in this study do not see themselves as part of the root cause of climate change but as contributing towards the solution, as well as cleaner production, merely by maintaining their business-as-usual. However, they name other industries and sectors (e.g. cement, steel, transport and agriculture) that have more net GHG emissions [E4, F5, F8, F9, F10]. Due to this presumed responsibility based on the 'root cause' of the problem, some companies would not want to

[6] Interview respondents mentioned both international and national trade associations including Swedenergy, Swedish Forest Industries Federation, Finnish Energy, Finnish Forests Association, and the Confederation of European Paper Industries.

implement measures such as BECCS so that other sectors with fossil emissions can continue their operations [E4, F5, F8, F9].

While companies try to balance contributing to an energy transition while ensuring that other sectors also undertake responsibility, making changes towards an energy transition is not new to the forestry and energy utility sectors in Sweden and Finland. The respondents emphasized a history of switching from fossil fuels to renewable alternatives [E3, E4, E6, E7, E8, E9, E10, F3, F5, F6, F8]. In both Sweden and Finland, the companies will continue to remove residual fossil fuels in transportation, industrial processes and/or logistics [E1, E6, E7, E9, F6, F8]. One company is investigating alternatives to carbon dense peat in its boilers, in addition to biomass-based substitutes for start-up oil and gas such as pyrolysis oil [E1]. According to this respondent, peat is necessary for corrosion resistance and to reduce deposit formation in the boilers.

Evidently, even though climate change is not perceived as caused by the companies in this study, they want to be part of the solution and contribute to national climate goals, in the words of one respondent:

> *Change is good but slow and with a clear strategy and direction, which is fine now with these climate goals /…/. For it is clear what is to come.* [E3]

The energy utility companies in this study see themselves as enablers for others to reach their climate goals – providing electricity, heat, and other products such as biogas – and focus on climate change measures other than BECCS [E3, E6, E7, E8]. One respondent discussed handling valuable raw materials like wood in a circular economy and only burning materials that cannot be used in other ways [E1]. This respondent also feels it could be more acceptable to burn biomass if carbon capture is implemented [E1]. Other company representatives said that taking care of waste streams, for example through energy recovery, increases the circular economy and integration of material flows in society [E3]. According to the energy companies in this study, this is especially true in the service provided by the handling and treating of municipal solid waste, which includes taking care of toxic materials [E2, E3, E7, E8, E9]. Several companies talked about circular economy and industrial symbiosis as means to increase resource efficiency and to reduce waste, including efforts to reuse and recycle products from the waste streams [E1, E5, E6, E9].

Burning waste has been under debate since it also contains a lot of fossil plastic materials, and a new tax was recently approved by the Swedish Parliament (2019) on each ton of burnt waste. Energy utilities discussed reducing plastic material waste through improved recycling practices, thereby reducing fossil CO_2 emissions [E3, E4, E8, E9]. Another energy company representative projects that circular economy will be a focus in the future, beyond thinking about sustainability [E6]. This company representative also mentioned the importance of maintaining a systems perspective and considering differences in the potential of CHP and heat pumps to reach net zero emissions in the future; heat pumps cannot implement BECCS [E6].

Correspondingly, the forestry sector companies in this study also focus on environmental aspects other than BECCS. One example of this is the growth of the forest and how this essentially means that forestry is already net-negative (if a LULUCF perspective is included in the balance) [F2, F5, F6, F7, F8, F9, F10]. Another example is in the calculation of substitution effects, i.e. in the replacement of fossil products such as cement and fossil plastic packaging with green products such as wood and paper packaging. Although these substitution effects are hard to evaluate, some companies are positive towards the development of calculation methods and tools in this area [F2, F5, F6, F8, F9, F10]. In addition, the idea of substitution effects synchronizes well with the forestry companies' ambitions to maximize the output from their feedstock [F2, F3, F5, F6, F7, F9].

Moreover, with an ongoing incremental development to increase production and efforts to keep up with regulation, companies are currently at different stages of development. While some are focused on improving the cleaning systems for process water [F3, F4], others are increasing efficiency and production [F3, F7, F9, F10] and/or taking better care of residual side streams [F4, F5, F7, F10]. In the larger forest industry companies, these synergies to take care of side streams take place through a company's existing business segments [F8].

Although the industry respondents are willing to contribute to addressing reduced net GHG emissions, they reiterate that it is not their responsibility to financially prioritize BECCS-related investments which could compete with their other environmental priorities. Nevertheless, several companies suggest that decreasing their CO_2 emissions to the atmosphere would benefit society, so they are willing to contribute [E6, E7, E8, F9].

4.3 Technical trade-offs of carbon capture

In the conversation around technical trade-offs with carbon capture technology, the main tensions outlined by respondents were reduced process efficiency and potential loss of sellable products (e.g. electricity, heat, biofuels, pulp and paper). The companies in this study have been focused on increasing energy efficiency and productivity for a long time [E1, E2, E3, E5, E6, E7, E8, E9, F3, F4, F5, F6, F7, F9, F10]. Conversely, implementing BECCS would lead to a decrease in efficiency since the capture process requires energy [E9]. Hence, process integration is an important factor [E1, E4, E5, E9, F10], as a higher level of integration could increase efficiency [E4]. Moreover, forest companies have increasingly made use of their by-products and side streams, either within the company or in collaborations; for example, in the production of biofuels from black liquor (e.g. tall oil) [F1, F3, F5, F6, F7, F10], lignin separation [F6, F7, F9, F10] or district heating synergies with municipalities [F1, F2, F6, F10]. In contrast, incorporating a CO_2 capture process could re-direct some of that biomass usage, and as such there is a trade-off to consider – which also includes the energy companies that use forestry residues as fuel [E1, E5, E6, E7, F5, F10].

Apart from the process integration and trade-off with efficiency and production, site specific factors that were discussed by respondents include land-requirements [E4, E7, F6] and legal barriers [E3, E4, E6, F9]. However, companies do not foresee that carbon capture technology would pose any specific technoeconomic risk to the other parts of the facility [E1, E5, E6, E7, E8, E9, F1, F5, F6]. Furthermore, as noted by respondents, it is easier to capture CO_2 from the streams where the concentration is the highest [E5]. For example, as one respondent of a paper company pointed out, carbon capture from the lime kiln could be more efficient due to the specific conditions of that flue gas stream [F5]. However, according to one respondent, it should not be a big problem to collect all the flue gas streams into one stack [E7].

Lock-in effects and timing of investment are important factors. Company representatives see the capture process as technically mature [E4, E5, E6, E7, E9] and possible to implement [E8, F8]. However, according to another respondent, all new technology entails some uncertainties [F7]. Correspondingly, company representatives discussed questions concerning the energy required

[E5, E9, F3], the handling of the gas [E5, E8] or other technical risks that have yet to become apparent [F2]. On some level, all these parameters contribute to the financial risk of investing in carbon capture technology within the industry, since respondents noted that large investments that are comparable to an investment in carbon capture technology (e.g. a new recovery boiler) are usually made on a 20 to 30-year time frame [E2, E5, E10, F5]. According to one respondent, if there was an instance where the new technology did not work properly and affected the main process, leading to a stop in production, then that could be a “huge” loss [F10]. Another company representative confirms that big investments of that type make companies less flexible for rapid changes [E10].

Several respondents point to a need for a CO_2 transportation infrastructure [E5, E8, F5, F7, F9], discussing possible collaborations with the government to realise this large-scale infrastructure investment [E8, E10, F9]. Another respondent stated that companies would have to work together to coordinate transport of CO_2, including shared ships and pumping stations [E6]. In addition, Norway was discussed by several respondents as a potential starting point for storage [E2, E4, E6, E7, E8, E9, F9], however, others raised concerns around the safety of the storage site [F3, F5]. Moreover, there could also be potential for domestic storage, but this would have to be investigated [E4, E6] and would likely need to employ competence from other storage projects, e.g. in Norway [F7]. Another respondent noted that a lack of domestic CO_2 storage locations available is a bigger barrier to BECCS than the technical carbon capture process [E1].

In response to these transportation and storage parameters, CCU options were discussed as alternative starting points on the way towards realizing BECCS [E3, F5, F7]. According to some company representatives, the important aspect here is that in CCU applications, there is a product to sell, in contrast to CCS and BECCS [F7, F9, F10].

> *At some point of course, we would need carbon capture as well. But we need to also have use for it, and there is not. Then again, we are talking about having an integration where you would have all kinds of industries that would use or that would need the CO_2, and they are not that many. That's the kind of issue here that you would then need to find ways of using the CO_2.* [F10]

CCU applications might therefore be more feasible according to some respondents, since it does not require transportation and storage of CO_2 [E2, E3, F5, F7]. In fact, some applications of CCU are already ongoing in form of production of precipitated calcium carbonate, which is used as filler for paper [F9]. Another company investigated an idea to capture CO_2 from the lime kiln and to produce methanol together with hydrogen from electrolysers. However, the electricity price was not low enough at the point of the investigation [F5].

In contrast, according to some companies, it could be an advantage to be a first mover on BECCS, especially since environmental concerns are increasing and sustainability targets can be rewarding to pursue [E4, F2]. That view motivates some companies to initiate R&D related to BECCS [E3, E4, E9, F2, F8, F9]. Meanwhile, others are still unwilling to be first movers [E2, E6, E10, F3, F4, F5, F9]. Paradoxically, one of the companies does not want to be a first mover but is conducting R&D [F9].

4.4 Lack of customer demands for negative emissions

For the companies in this study, responding to customer preferences and demands while also managing their finances and sustainable business models can be a challenge. For many companies, sustainability is a well-established part of the marketing framework. The marketing of forestry products includes a focus on societal contributions and mirrors a sustainable and active forestry sector [F1, F2, F5, F7, F8, F9], while resource efficiency and energy recovery are highlighted by energy utilities [E3, E4, E5, E6, E7, E9]. One company mentioned the importance of psychology in marketing, stating that impacting individuals' behaviours when sorting waste and recyclables plays a key role in reducing emissions [E6]. In this example, changing a waste bin's label from "combustibles" to "not sortable," led to a 20% decrease in waste volume and an increase in recycled materials. Marketing psychology could also be relevant for reducing emissions through BECCS. Even though there can be benefits to marketing sustainability aspects, there can be trade-offs between environmental and financial targets according to some energy utility companies [E2, E3]. Sustainability goes hand in hand with other company priorities, as one respondent said:

> *We call it 'triple baseline', meaning that at the bottom of our financial accounts it should say that we have been good for the society, environment and economy. This is so that we may endure in the future and continue to do good.* [F9]

When it comes to BECCS, most companies have not contemplated on negative emissions' impact on the marketing of products, and while some thought it could be advantageous for marketing purposes [E2, E4, E6, E9, F1, F4, F6], others questioned the added benefit of marketing negative emissions [E7, F5, F9, F10]. Another respondent stated that CCS could have a stronger marketing advantage in other sectors like cement or steel [F9].

Nevertheless, pressure from customers impacts companies' actions on climate change [E3, E7, F3, F4, F9], which is relevant in the context of BECCS as a possible mitigation measure. One company emphasized partnerships with customers and building trust [E6]. Collaboration across the supply chain is seen as key to communicate and address customers' demands [F2]. Although customers do place demands on climate and environmental related issues according to a company representative, these demands include fossil GHG emissions, water emissions, and ecological certifications [F3]. A demand for BECCS from customers is absent. At the same time, another respondent made a reference to marketing research by claiming that 15% of customers are willing to pay more for an ecological product while the other 85% are not, suggesting that the same could apply for customers' willingness to pay for products with BECCS [F9]. The companies' views on customers' requests for negative emissions could impact the type of climate responsibility they decide to shoulder [F2, F10].

In addition to company sustainability priorities, there are sustainability certifications that could contribute to marketing advantages and highlight a company's commitment to a sustainable society. One such certification is by the Forest Stewardship Council (FSC) mentioned in interviews [E4, E7, F5, F7]. The FSC is an international organisation that certifies sustainable forest management, and it has established criteria for managing forests and associated supply chains (FSC, 2020). Customers' sustainability concerns and certification preferences, such as FSC, impact how companies' market their products and design their strategies.

5. Discussion

The analysis of the interview material has shown that the most important conditions highlighted by the companies, when considering the potential for BECCS, focus around four main tensions. First, there is a lack of policies around negative emissions and BECCS, both internationally and nationally, so there is no incentive to invest in BECCS (see section 2.2 for background on the political context). Second, focusing on their small share of fossil emissions, companies do not feel that they should be expected to go beyond their current sustainability efforts, even though point sources of biogenic emissions have potential for BECCS. Third, BECCS could lead to technical trade-offs by reducing efficiency and production, in addition to impacting the industry investment cycle (see section 2.3 for background on the industrial context). And fourth, a lack of customer demands for negative emissions could make it hard for companies to prioritize investments in carbon capture technology in their sustainability strategies.

Even though BECCS is considered to be an economically attractive climate change mitigation option according to top down modelling studies (e.g. Azar *et al.*, 2006; Mandova *et al.*, 2019; Rogelj *et al.*, 2018), BECCS is not seen as an economical option among interviewed companies, unless there are enabling policies. Financial mechanisms in policies, on the national or EU-level, could enable BECCS, although there are currently few policies that support its development and implementation (Fridahl and Lehtveer, 2018). When discussing barriers to BECCS, the companies in this study focused very little on challenges like social acceptance and ethics which are often highlighted as a key barrier, such as the location and safety of carbon storage sites (Cox *et al.*, 2018). The main location for storage mentioned by companies is offshore in deep saline aquifers in Norway to which the CO_2 would be transported by ships, but respondents also mentioned that offshore sites near Gotland, Sweden also have potential for future storage.

According to a public perception study, this offshore storage is more favourable than onshore CO_2 storage including pipelines (Dütschke *et al.*, 2016). The main barrier discussed by companies in this study remains the high costs of BECCS, which is similar to the findings by Karimi and Komendantova (2015) that in Norway and Finland, where there is moderate opposition to BECCS, concerns focus on investment risk. One difference between Finland and Sweden is that the Finnish companies discussed carbon sinks which was not brought up by any of the Swedish companies in this study. This could stem from politics – Finland emphasizes strengthening LULUCF sinks to meet its carbon neutral goal (Ministry of the Environment in Finland, 2017) while Sweden's net-zero target does not rely on these sinks (SOU, 2020:4).

This concern about financing BECCS depends on the system boundaries, such as which part of the system would companies be responsible for, and where would other actors contribute, which leads to the second tension about responsibility. Even though the Swedish and Finnish governments have identified large point sources of biogenic emissions as having potential for BECCS ('Finland's 7th National Communication under the UNFCCC,' 2017; SOU, 2020:4), the companies operating these facilities do not feel responsible for climate change based on the interviews in this study. The energy utilities are at the end of the supply chain addressing the problem of waste, while the forest industry companies do not consider themselves as large net GHG emitters, since they often also are in the control of the forests which provide the feedstock to their processes. When factoring in LULUCF and emissions avoided through substitution effects in their products, forestry could already be carbon negative (Holmgren and Kolar, 2019). Forestry companies in both Sweden and Finland mentioned a need for more scientific research to evaluate the impact of substitution effects on climate change. This knowledge gap about understanding linkages between forest management and climate mitigation is being explored (e.g. Lundmark *et al.*, 2014).

In addition, the companies in this study already have a clear focus on reducing climate impact with conventional mitigation measures other than BECCS. Contributing to a circular economy is a growing interest area mentioned by many energy companies in this study, and the forestry sector's discussions about efficient use of resources and utilising side-streams aligns with circular economy discussions in Finland (Näyhä, 2019). Furthermore, a focus on cleaner production by decreasing the amount of plastic/fossil sources in waste incineration plants is a main priority among energy utilities in this study.

While it is technically possible to implement BECCS, there are both site and industry specific factors to consider that can lead to technical trade-offs. In addition to reduced efficiency of the power plant or paper mill, the possibility to integrate the carbon capture process within the facility could contribute to the success or failure of the technology. This is because more heavily integrated designs for carbon capture could lead to a more efficient process. At the same time, it is important that not so heavily integrated post-combustion carbon capture applications can be retrofitted to an existing plant and are easy to disconnect. This relates to the fear of locking into a technology that is not successful and, as such, effects the willingness of being first movers. Another factor is that while starting small might have benefits pertaining to the efficiency of the capture process, not taking a holistic approach will increase the specific cost of transportation and storage (Kjärstad *et al.*, 2016). In contrast, taking a holistic approach by capturing large amounts of CO_2, even though it is more cost-efficient, will increase the investment cost (Onarheim *et al.*, 2017a). As such, when considering the need for an infrastructure to then transport and store the CO_2, it is no surprise that the companies involved in this study mentioned other alternatives, e.g. CCU. Several studies on the potential of CCU in a Nordic context also point towards this development pathway of using CO_2 as raw material (Karjunen *et al.*, 2017; Kuparinen *et al.*, 2019; Patricio *et al.*, 2017a; Patricio *et al.*, 2017b).

Finally, there is a constant balancing for companies to communicate with customers and shareholders while keeping up with national and international climate goals. Customer and authorities' demands influence company strategies which is shown by Haraldsson and Johansson (2019) where customers can drive energy efficiency improvements. Similar to the findings by Näyhä (2019), the companies in this study have customers that are on a spectrum of environmental consciousness. Even though customer demand is too subtle to motivate the entire industry, some of the companies in this study are considering BECCS. The companies' marketing strategies exclude BECCS but rather highlight sustainability, reducing fossil CO_2 emissions, improving energy efficiency, and providing alternatives to fossil products by utilising paper.

This mismatch to fit BECCS into the existing sustainability framework is perhaps most noticeable within the forest industry, and carbon capture is currently not included in most companies' formal sustainability documents or websites. Even though, it is a climate change measure that many companies are discussing internally. On one hand, customers have the capability of impacting company investments and changes, so their engagement could be relevant in the context of BECCS (Hietala *et al.*, 2019). On the other hand, a lack of demand from customers and shareholders for negative emissions could delay BECCS from becoming a strategic investment priority. Customers have focused on the value of certifications such as FSC in this study and in a study by Näyhä (2019) in Finland. As such, maybe negative emissions certifications could become desirable by customers and therefore advantageous for companies in the future. It remains a question about what will come first to spark interest in carbon capture: pressure from customers, the government, or even within companies themselves.

6. Conclusions

This qualitative study set out to explore the perspectives of key companies within the forestry and energy utility sectors in Finland and Sweden, to understand their views on BECCS and emerging tensions in the energy transition, and to fill the gap of a lack of bottom-up studies on BECCS. This study includes perspectives from 20 of the 24 companies operating the facilities with the largest point sources of biogenic CO_2 emissions in the two countries. Companies perceive BECCS as one option among several climate change mitigation measures in the political landscape.

Finland and Sweden have large point sources of biogenic emissions, mainly chemical pulp mills and district heating plants, where BECCS could be implemented. However, there are challenges beyond technology development according to the interviewed companies. From a company perspective, the most significant barrier to implementing BECCS is the lack of economic incentive: either through national or international policies, political support is seen as necessary if BECCS is to be realised. This means that reducing net GHG emissions through BECCS would require government intervention. Other barriers and driving forces from companies´ perspective include sense of responsibility, technological trade-offs, and consumer and shareholder preferences. Companies perceive that they already are and will continue to contribute to national climate goals, and their climate change strategies for cleaner production include energy efficiency measures; substitution of fossil fuels with biomass for energy and consumer products; and sustainable forestry management. In contrast, some companies have sought financial support to conduct studies or pilot carbon capture methods, including Stora Enso and Stockholm Exergi (SEA, 2020c). However, most of the companies in this study do not see BECCS as a realistic solution for at least another decade. This implies that BECCS is perceived as an expensive and futuristic solution, and most companies are unwilling to compromise other sustainability priorities to focus on reducing biogenic CO_2 emissions. This could lead to delays in achieving national and international climate goals, but it also means that there are fundamental barriers to reducing net CO_2 emissions and to implementing BECCS. Overcoming this barrier would require imminent collaborations between government, industry actors and their customers to develop and implement pathways to reduce net CO_2 emissions in sustainable ways.

Further research could seek to understand how the technical integration of carbon capture technology at industrial facilities could work and to study how the political landscape influences how carbon capture technology could contribute towards a net-negative emissions future. In addition, research could investigate companies' perspectives on different solutions to decrease GHG emissions since there could be innovative opportunities to integrate industrial sectors to promote more sustainable industries in the future.

Acknowledgement

The work has been carried out within the scope of the Graduate School in Energy Systems, financed by the Swedish Energy Agency and MESAM under the project, 'An integrative systems approach to a carbon neutral industry'. This research was supported by the Swedish Energy

Agency [grants 46222-1 and 46036-1]; Formas – The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning [grant 2016-00958]; and the Swedish Research Council [grant 2016-06359]. We would also like to thank the company representatives who participated in this study, extend appreciation to colleagues who contributed feedback on the text, and thank the Linköping University Library for covering the costs to make this article open access.

Bibliography

Anderson, K. and Peters, G., 2016. 'The trouble with negative emissions', *Science,* 354(6309), pp. 182-183. https://doi.org/10.1126/science.aah4567

Azar, C., Lindgren, K., Larson, E. and Möllersten, K., 2006. 'Carbon Capture and Storage From Fossil Fuels and Biomass – Costs and Potential Role in Stabilizing the Atmosphere', *Climatic Change,* 74(1-3), pp. 47-79. https://doi.org/10.1007/s10584-005-3484-7

Azar, C., Lindgren, K., Obersteiner, M., Riahi, K., van Vuuren, D. P., den Elzen, K. M. G. J., Möllersten, K. and Larson, E. D., 2010. 'The feasibility of low CO2 concentration targets and the role of bio-energy with carbon capture and storage (BECCS)', *Climatic Change,* 100(1), pp. 195-202. https://doi.org/10.1007/s10584-010-9832-7

Beck, S. and Mahony, M., 2018. 'The IPCC and the new map of science and politics', *Wiley Interdisciplinary Reviews: Climate Change,* 9(e547), pp. 1-16. https://doi.org/10.1002/wcc.547

Braunreiter, L. and Bennett, S. J., 2017. 'The neglected importance of corporate perceptions and positions for the long-term development of CCS', *Energy Procedia,* 114, pp. 7197-7204. https://doi.org/10.1016/j.egypro.2017.03.1825

Bui, M., Adjiman, C. S., Bardow, A., Anthony, E. J., Boston, A., Brown, S., Fennell, P. S., Fuss, S., Galindo, A., Hackett, L. A., Hallett, J. P., Herzog, H. J., Jackson, G., Kemper, J., Krevor, S., Maitland, G. C., Matuszewski, M., Metcalfe, I. S., Petit, C., Puxty, G., Reimer, J., Reiner, D. M., Rubin, E. S., Scott, S. A., Shah, N., Smit, B., Trusler, J. P. M., Webley, P., Wilcox, J. and Mac Dowell, N., 2018. 'Carbon capture and storage (CCS): the way forward', *Energy & Environmental Science,* 11(5), pp. 1062-1176. https://doi.org/10.1039/c7ee02342a

Campbell-Árvai, V., Bessette, D., Kenny, L. and Arvai, J., 2019. 'Improving decision making for carbon management initiatives', *International Journal Risk Assessment and Management,* 22(3/4), pp. 342-358. https://doi.org/10.1504/ijram.2019.103338

Cox, E. M., Pidgeon, N., Spence, E. and Thomas, G., 2018. 'Blurred lines: the ethics and policy of greenhouse gas removal at scale', *Frontiers in Environmental Science,* 6, pp. 1-7. https://doi.org/10.3389/fenvs.2018.00038

Darda, S., Papalas, T. and Zabaniotou, A., 2019. 'Biofuels journey in Europe: Currently the way to low carbon economy sustainability is still a challenge', *J. Clean. Prod.*, 208, pp. 575-588. https://doi.org/10.1016/j.jclepro.2018.10.147

Dütschke, E., Wohlfarth, K., Höller, S., Viebahn, P., Schumann, D. and Pietzner, K., 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, pp. 149-159. https://doi.org/10.1016/j.ijggc.2016.07.043

EC, European Commission, 2020. *European IPCC Bureau.* Brussels. Available at: https://eippcb.jrc.ec.europa.eu/about (Accessed: 5 May 2020).

EEA, European Environment Agency, 2013. *Municipal waste management in Finland*. Available at: https://www.eea.europa.eu/publications/managing-municipal-solid-waste/finland-municipal-waste-management/view (Accessed: 24 May 2020).

EEA, European Environment Agency, 2019. *European Pollutant Release and Transfer Register (E-PRTR)*. Available at: https://prtr.eea.europa.eu/#/home (Accessed: 13 June 2019).

EP, European Parliament, 2009. *Renewable Energy Directive.* Brussels (Directive 2009/28/EC). Available at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32009L0028 (Accessed: 24 May 2020).

EP, European Parliament, 2010. *EU Industrial Emissions Directive (IED).* Brussels (2010/75/EU). Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1579185869463&uri=CELEX:32010L0075 (Accessed: 24 May 2020).

Ericsson, K., Huttunen, S., Nilsson, L. J. and Svenningsson, P., 2004. 'Bioenergy policy and market development in Finland and Sweden', *Energy Policy,* 32(15), pp. 1707-1721. https://doi.org/10.1016/S0301-4215(03)00161-7

Eurostat, 2019. *Geographical Information and Maps (GISCO), Countries 2016, shp format*. Available at: https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/countries (Accessed: 26 May 2020).

Fauré, E., Finnveden, G. and Gunnarsson-Östling, U., 2019. 'Four low-carbon futures for a Swedish society beyond GDP growth', *J. Clean. Prod.,* 236. https://doi.org/10.1016/j.jclepro.2019.07.070

'Finland's 7th National Communication under the UNFCCC', 2017. Helsinki: Ministry of the Environment and Statistics Finland.

Finnish Forest Industries, 2020. *Finnish exports*. Helsinki. Available at: https://www.forestindustries.fi/statistics/forest-industry/ (Accessed: 24 May 2020).

Fridahl, M. and Bellamy, R., 2018. 'Multilevel policy incentives for BECCS in Sweden', in Fridahl, M. (ed.) *Bioenergy with carbon capture and storage: From global potentials to domestic realities*. Brussels: European Liberal Forum, pp. 57-67.

Fridahl, M. and Lehtveer, M., 2018. 'Bioenergy with carbon capture and storage (BECCS): Global potential, investment preferences, and deployment barriers', *Energy Research & Social Science*, 42, pp. 155-165. http://doi.org/10.1016/j.erss.2018.03.019

FSC, 2020. *Forest Stewardship Council*. Bonn. Available at: https://fsc.org/en (Accessed: 5 May 2020).

Fuss, S., Lamb, W., Callaghan, M., Hilaire, J., Creutzig, F., Amann, T., Beringer, T., de Oliveira Garcia, W., Hartmann, J., Khanna, T., Luderer, G., Nemet, G., Rogelj, J., Smith, P., Vicente, J., Wilcox, J., Dominquez, M. and Minx, J., 2018. 'Negative emissions–Part 2: Costs, potentials, and side effects', *Environmental Research Letters*, 13(6), pp. 1-47. https://doi.org/10.1088/1748-9326/aabf9f

Garðarsdóttir, S. Ó., Normann, F., Skagestad, R. and Johnsson, F., 2018. 'Investment costs and CO2 reduction potential of carbon capture from industrial plants – A Swedish case study', *International Journal of Greenhouse Gas Control*, 76, pp. 111-124. https://doi.org/10.1016/j.ijggc.2018.06.022

Geden, O. and Schenuit, F., 2019. 'Climate neutrality as long-term strategy: The EU's net zero target and Its consequences for member states', *German Institute for International and Security Affairs,* 33(August), pp. 1-4. https://doi.org/10.18449/2019C33

Grönkvist, S., Bryngelsson, M. and Westermark, M., 2006. 'Oxygen efficiency with regard to carbon capture', *Energy,* 31(15), pp. 3220-3226. https://doi.org/10.1016/j.energy.2006.03.002

Gronow, A. and Ylä□Anttila, T., 2019. 'Cooptation of ENGOs or treadmill of production? Advocacy coalitions and climate change policy in Finland', *Policy Studies Journal,* 47(4), pp. 860-881. https://doi.org/10.1111/psj.12185

Gunderson, R., Stuart, D. and Petersen, B., 2020. 'The fossil fuel industry's framing of carbon capture and storage: Faith in innovation, value instrumentalization, and status quo maintenance', *J. Clean. Prod.*, 252, pp. 1-9. https://doi.org/10.1016/j.jclepro.2019.119767

Haikola, S., Hansson, A. and Anshelm, J., 2019. 'From polarization to reluctant acceptance–bioenergy with carbon capture and storage (BECCS) and the post-normalization of the climate debate', *Journal of Integrative Environmental Sciences,* 16(1), pp. 45-69. https://doi.org/10.1080/1943815x.2019.1579740

Hansson, A., Fridahl, M., Haikola, S., Yanda, P., Pauline, N. and Mabhuye, E., 2020. 'Preconditions for bioenergy with carbon capture and storage (BECCS) in sub-Saharan Africa: the case of Tanzania', *Environment, Development and Sustainability,* 22, pp. 6851-6875. https://doi.org/10.1007/s10668-019-00517-y

Haraldsson, J. and Johansson, M., 2019. 'Energy Efficiency in the Supply Chains of the Aluminium Industry: The Cases of Five Products Made in Sweden', *Energies,* 12(2). https://doi.org/10.3390/en12020245

Haszeldine, R. S., Flude, S., Johnson, G. and Scott, V., 2018. 'Negative emissions technologies and carbon capture and storage to achieve the Paris Agreement commitments', 376(20160447), pp. 1-23. https://doi.org/10.1098/rsta.2016.0447

Hietala, J., Hänninen, R., Kniivilä, M. and Toppinen, A., 2019. 'Strategic Management Towards Competitive Advantage—Patterns of Internationalization in the Finnish and Swedish Sawmill Industries', *Current Forestry Reports*, 5(4), pp. 199-209. https://doi.org/10.1007/s40725-019-00100-8

Holmgren, P. and Kolar, K., 2019. ‘Reporting the overall climate impact of a forestry corporation - the case of SCA’: SCA. Available at: https://www.sca.com/globalassets/sca/hallbarhet/klimatnytta/rapport.pdf.

IEA, 2018. ‘World energy balances: Overview’: International Energy Agency.

IPCC, 2005. 'Technical Summary', in Metz, B., Davidson, O., de Coninck, H., Loos, M. and Meyer, L. (eds.) *IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change* Cambridge: Cambridge Univeristy Press.

Kapetaki, Z. and Scowcroft, J., 2017. 'Overview of carbon capture and storage (CCS) demonstration project business models: Risks and enablers on the two sides of the Atlantic', *Energy Procedia*, 114, pp. 6623-6630. https://doi.org/10.1016/j.egypro.2017.03.1816

Karimi, F. and Komendantova, N., 2015. 'Understanding experts’ views and risk perceptions on carbon capture and storage in three European countries', *GeoJournal*, 82(1), pp. 185-200. https://doi.org/10.1007/s10708-015-9677-8

Karjunen, H., Tynjälä, T. and Hyppänen, T., 2017. 'A method for assessing infrastructure for CO2 utilization: A case study of Finland', *Applied Energy*, 205, pp. 33-43. https://doi.org/10.1016/j.apenergy.2017.07.111

Kefford, B. M., Schmeda-Lopez, D. R., Stringer, M., Greig, C., Smart, S., Small, M. J. and Wong-Parodi, G., 2018. ‘Identifying regionally dependent barriers in the carbon capture and storage industry’: Dow Centre for Sustainable Engineering Innovation. Available at: https://espace.library.uq.edu.au/view/UQ:728614/UQ728614_OA.pdf?dsi_version=4c89929e3dad69499f1d53e99987497c.

Kjärstad, J., Skagestad, R., Eldrup, N. H. and Johnsson, F., 2016. 'Ship transport—A low cost and low risk CO2 transport option in the Nordic countries', *International Journal of Greenhouse Gas Control*, 54, pp. 168-184. https://doi.org/10.1016/j.ijggc.2016.08.024

Kuparinen, K., Vakkilainen, E. and Tynjälä, T., 2019. 'Biomass-based carbon capture and utilization in kraft pulp mills', *Mitigation and Adaptation Strategies for Global Change*, pp. 1213-1230. http://doi.org/10.1007/s11027-018-9833-9

Kvale, S. and Brinkmann, S., 2009. *InterViews: Learning the craft of qualitative research interviewing.* Los Angeles: Sage Publications.

Lauri, K., Jouko, R., Nicklas, N. and Sebastian, T., 2014. 'Scenarios and new technologies for a North-European CO2 transport infrastructure in 2050', *Energy Procedia*, 63, pp. 2738-2756. https://doi.org/10.1016/j.egypro.2014.11.297

Levihn, F., Linde, L., Gustafsson, K. and Dahlen, E., 2019. 'Introducing BECCS through HPC to the research agenda: The case of combined heat and power in Stockholm', *Energy Reports*, 5, pp. 1381-1389. https://doi.org/10.1016/j.egyr.2019.09.018

Livingston, J., 2018. *Climate science for policy? The knowledge politics of the IPCC after Copenhagen.* PhD, Lund University, Lund [Online] Available at: http://lup.lub.lu.se/search/ws/files/53831543/Jasmine_Livingston.pdf (Accessed: 24 May 2020).

Lövin, I. and Wallström, M., Department of Environment and Energy [Miljö- och energidepartementet], 2017. *A climate policy framework for Sweden [Ett klimatpolitiskt ramverk för Sverige]*. Stockholm: Government Offices [Regeringskansliet] (Prop. 2016/17:146). Available at: https://www.regeringen.se/49fe25/contentassets/480ed767687b4b7ba6c960f9c1d4857f/ett-klimatpolitiskt-ramverk-for-sverige-prop.-201617146 (Accessed: 24 May 2020).

Lundmark, T., Bergh, J., Hofer, P., Lundström, A., Nordin, A., Poudel, B., Sathre, R., Taverna, R. and Werner, F., 2014. 'Potential Roles of Swedish Forestry in the Context of Climate Change Mitigation', *Forests*, 5(4), pp. 557-578. http://doi.org/10.3390/f5040557

Mandova, H., Patrizio, P., Leduc, S., Kjärstad, J., Wang, C., Wetterlund, E., Kraxner, F. and Gale, W., 2019. 'Achieving carbon-neutral iron and steelmaking in Europe through the deployment of bioenergy with carbon capture and storage', *J. Clean. Prod.*, 218, pp. 118-129. https://doi.org/10.1016/j.jclepro.2019.01.247

Ministry of the Environment in Finland, 2017. *Government report on medium-term climate change policy plan for 2030: Towards climate-smart day-to-day living.* Helsinki: Ministry of the Environment (Finland 21en). Available at: http://urn.fi/URN:ISBN:978-952-11-4752-4.

Näyhä, A., 2019. 'Transition in the Finnish forest-based sector: Company perspectives on the bioeconomy, circular economy and sustainability', *J. Clean. Prod.*, 209, pp. 1294-1306. http://doi.org/10.1016/j.jclepro.2018.10.260

Nemet, G. F., Callaghan, M. W., Creutzig, F., Fuss, S., Hartmann, J., Hilaire, J., Lamb, W. F., Minx, J. C., Rogers, S. and Smith, P., 2018. 'Negative emissions—Part 3: Innovation and upscaling', *Environmental Research Letters*, 13(6), pp. 1-30. https://doi.org/10.1088/1748-9326/aabff4

Nisbet, M. C., 2019. ‘The carbon removal debate: Asking critical questions about climate change futures’ [Carbon Removal Briefing Paper], Washington, DC: Institute for Carbon Removal Law and Policy. Available at: https://www.american.edu/sis/centers/carbon-removal/upload/carbon-removal-debate.pdf (Accessed: 24 May 2020).

Nordic Council of Ministers, 2019. *Declaration on Nordic climate neutrality*. Available at: https://www.regjeringen.no/contentassets/ff55fbdf4ce74ec3ac3e473f62a673a7/declarationonnordiccarbonneutralitysigned.pdf (Accessed: 8 May 2020).

Official Statistics of Finland, 2018. *Greenhouse gases [e-publication]*. Helsinki: Statistics Finland. Available at: http://tilastokeskus.fi/til/khki/2018/khki_2018_2019-12-12_tie_001_en.html (Accessed: 12 March 2020).

Official Statistics of Finland, 2019. *Energy Year 2018, section 4.2: Fuel consumption in production of district heat [e-publication]*. Helsinki: Statistics Finland. Available at: https://pxhopea2.stat.fi/sahkoiset_julkaisut/energia2019/html/engl0003.htm (Accessed: 24 May 2020).

Official Statistics of Sweden, 2019. *Territorial emissions and uptake of greenhouse gases [Territoriella utsläpp och upptag av växthusgaser]*. Stockholm: Swedish Environmental Protection Agency. Available at: https://www.naturvardsverket.se/Sa-mar-miljon/Statistik-A-O/Vaxthusgaser-territoriella-utslapp-och-upptag/ (Accessed: 12 March 2020).

Onarheim, K., Mathisen, A. and Arasto, A., 2015. 'Barriers and opportunities for application of CCS in Nordic industry—A sectorial approach', *International Journal of Greenhouse Gas Control*, 36, pp. 93-105. https://doi.org/10.1016/j.ijggc.2015.02.009

Onarheim, K., Santos, S., Kangas, P. and Hankalin, V., 2017a. 'Performance and cost of CCS in the pulp and paper industry part 2: Economic feasibility of amine-based post-combustion CO2 capture', *International Journal of Greenhouse Gas Control*, 66, pp. 60-75. http://doi.org/10.1016/j.ijggc.2017.09.010

Onarheim, K., Santos, S., Kangas, P. and Hankalin, V., 2017b. 'Performance and costs of CCS in the pulp and paper industry part 1: Performance of amine-based post-combustion CO2 capture', *International Journal of Greenhouse Gas Control*, 59, pp. 58-73. http://doi.org/10.1016/j.ijggc.2017.02.008

Patricio, J., Angelis-Dimakis, A., Castillo-Castillo, A., Kalmykova, Y. and Rosado, L., 2017a. 'Method to identify opportunities for CCU at regional level — Matching sources and receivers', *Journal of CO2 Utilization*, 22, pp. 330-345. http://doi.org/10.1016/j.jcou.2017.10.009

Patricio, J., Angelis-Dimakis, A., Castillo-Castillo, A., Kalmykova, Y. and Rosado, L., 2017b. 'Region prioritization for the development of carbon capture and utilization technologies', *Journal of CO2 Utilization*, 17, pp. 50-59. http://doi.org/10.1016/j.jcou.2016.10.002

Rasmussen, J., 2020. *Management control for sustainability: Activities and procedures for energy management in industrial companies.* PhD, Linköping University, Linköping [Online] Available at: http://liu.diva-portal.org/smash/get/diva2:1377709/FULLTEXT01.pdf (Accessed: 24 May 2020).

Rogelj, J., Shindell, D., Jiang, K., Fifita, S., Forster, P., Ginzburg, V., Handa, C., Kheshgi, H., Kobayashi, S., Kriegler, E., Mundaca, L., Séférian, R. and Vilariño, M. V., 2018. ‘Mitigation pathways compatible with 1.5°C in the context of sustainable development. In: Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty’. Available at: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/02/SR15_Chapter2_Low_Res.pdf (Accessed: 24 May 2020).

Rydén, M., Lyngfelt, A., Langørgen, Ø., Larring, Y., Brink, A., Teir, S., Havåg, H. and Karmhagen, P., 2017. 'Negative CO2 Emissions with Chemical-Looping Combustion of Biomass – A Nordic Energy

Research Flagship Project', *Energy Procedia,* 114, pp. 6074-6082. https://doi.org/10.1016/j.egypro.2017.03.1744

Saldaña, J., 2013. *The coding manual for qualitative researchers.* 2 edn. London: SAGE.

SEA, Swedish Energy Agency, 2006. *Economic instruments in the energy sector: An evaluation of its effects on carbon dioxide emissions since 1990 [Ekonomiska styrmedel i energisektorn: En utvärdering av dess effekter på koldioxidutsläppen från 1990]*. Eskilstuna: Energimyndigheten (ER 2006:06).

SEA, Swedish Energy Agency, 2010. *A systems study of the opportunities to establish an infrastructure for CCS in the Baltic Sea region [Systemstudie av möjligheter att etablera en infrastruktur for CCS i Östersjöregionen]*. Eskilstuna: Energimyndigheten. Available at: http://kth.diva-portal.org/smash/record.jsf?pid=diva2%3A775207&dswid=7671 (Accessed: 24 May 2020).

SEA, Swedish Energy Agency, 2020a. *Energy in Sweden 2020 [Energiläget i siffror 2020]*. Eskilstuna: Energimyndigheten. Available at: http://www.energimyndigheten.se/statistik/energilaget/?currentTab=1#mainheading.

SEA, Swedish Energy Agency, 2020b. *Facts about the electricity certificate system [Fakta om elcertifikatsystemet]*. Eskilstuna: Energimyndigheten (ET 2020:3). Available at: https://energimyndigheten.a-w2m.se/Home.mvc?ResourceId=160397 (Accessed: 24 May 2020).

SEA, Swedish Energy Agency, 2020c. *New projects will contribute to negative emissions of greenhouse gases [Nya projekt ska bidra till negativa utsläpp av växthusgaser]*. Eskilstuna: Energimyndigheten. Available at: http://www.energimyndigheten.se/nyhetsarkiv/2020/nya-projekt-ska-bidra-till-negativa-utslapp-av-vaxthusgaser/.

Smith, P., Davis, S. J., Creutzig, F., Fuss, S., Minx, J., Gabrielle, B., Kato, E., Jackson, R. B., Cowie, A., Kriegler, E., van Vuuren, D. P., Rogelj, J., Ciais, P., Milne, J., Canadell, J. G., McCollum, D., Peters, G., Andrew, R., Krey, V., Shrestha, G., Friedlingstein, P., Gasser, T., Grübler, A., Heidug, W. K., Jonas, M., Jones, C. D., Kraxner, F., Littleton, E., Lowe, J., Moreira, J. R., Nakicenovic, N., Obersteiner, M., Patwardhan, A., Rogner, M., Rubin, E., Sharifi, A., Torvanger, A., Yamagata, Y., Edmonds, J. and Yongsung, C., 2015. 'Biophysical and economic limits to negative CO2 emissions', *Nature Climate Change,* 6, pp. 42-50. http://doi.org/10.1038/nclimate2870

SOU, Governmental inquiry [Statens Offentliga Utredningar], 2020:4. *The pathway to a climate- positive future – strategy and action plan for achieving negative greenhouse gas emissions after 2045 [Vägen till en klimatpositiv framtid]*. Stockholm: Government Offices [Regeringskansliet]. Available at: https://www.regeringen.se/rattsliga-dokument/statens-offentliga-utredningar/2020/01/sou-20204/ (Accessed: 24 May 2020).

Sovacool, B. K., 2017. 'Contestation, contingency, and justice in the Nordic low-carbon energy transition', *Energy Policy,* 102, pp. 569-582. https://doi.org/10.1016/j.enpol.2016.12.045

Swedish EPA, 2005. *A strategy for sustainable waste management.* Stockholm: Naturvårdsverket. Available at: https://www.naturvardsverket.se/Documents/publikationer/620-1249-5.pdf (Accessed: 6 May 2020).

Swedish Forest Industries, 2020. *Facts & Figures*. Stockholm: Skogsindustrierna. Available at: https://www.forestindustries.se/forest-industry/facts-and-figures/ (Accessed: 5 May 2020).

Swedish Parliament, 2019. *The Tax Committee's report 2019/20: SkU12: Tax on waste incineration [Skatteutskottets betänkande 2019/20:SkU12: Skatt på avfallsförbränning]*. Stockholm: Sveriges Riksdag. Available at: https://data.riksdagen.se/fil/B008D5B9-4829-4B08-931D-D7A942CE2CD7 (Accessed: 6 May 2020).

Thollander, P. and Ottosson, M., 2010. 'Energy management practices in Swedish energy-intensive industries', *J. Clean. Prod.,* 18(12), pp. 1125-1133. https://doi.org/10.1016/j.jclepro.2010.04.011

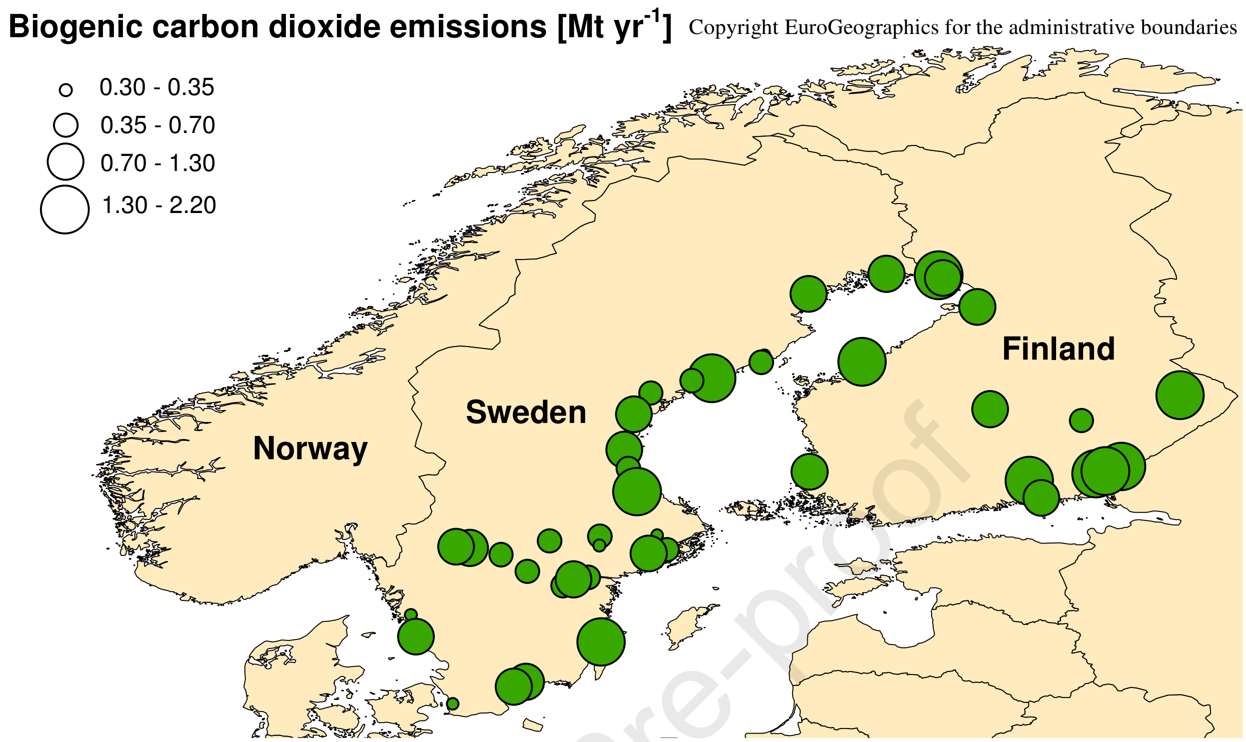
UN, 2017. *Sweden's goal – becoming the world's first fossil-free welfare state*. Sustainable Development Goals Partnership Platform: United Nations. Available at: https://sustainabledevelopment.un.org/partnership/?p=33918 (Accessed: 20 February 2020).

UN, 2019. *Finland will achieve carbon neutrality by 2035*. Sustainable Development Goals Partnership Platform: United Nations. Available at: https://sustainabledevelopment.un.org/partnership/?p=33186 (Accessed: 20 February 2020).

van Vuuren, D. P., Hof, A. F., van Sluisveld, M. A. E. and Riahi, K., 2017. 'Open discussion of negative emissions is urgently needed', *Nature Energy,* 2(12), pp. 902-904. https://doi.org/10.1038/s41560-017-0055-2

Wennersten, R., Sun, Q. and Li, H., 2015. 'The future potential for Carbon Capture and Storage in climate change mitigation – an overview from perspectives of technology, economy and risk', *J. Clean. Prod.*, 103, pp. 724-736. https://doi.org/10.1016/j.jclepro.2014.09.023

Werner, S., 2017. 'District heating and cooling in Sweden', *Energy,* 126, pp. 419-429. https://doi.org/10.1016/j.energy.2017.03.052


Biogenic carbon dioxide emissions [Mt yr-1]
Copyright EuroGeographics for the administrative boundaries
0.30 - 0.35
0.35 - 0.70
0.70 - 1.30
1.30 - 2.20
Norway
Sweden
Finland

Highlights

- BECCS discussions are on the horizon, but few companies are first movers.
- Large-scale deployment of BECCS would require political and financial support.
- Swedish and Finnish companies lack customer demand for negative emissions.
- There are trade-offs between energy efficiency and carbon capture.
- Companies consider BECCS as one of many climate change mitigation measures.

Abstract

Sweden and Finland have national goals to reach net negative greenhouse gas emissions before mid-century. Achieving these ambitious goals could employ negative emission technologies, such as bioenergy with carbon capture and storage, but it is unclear how this technology could be realized in an energy transition. Sweden and Finland stand out for having a large share of substantial point source emissions of biogenic carbon dioxide, in the production of pulp, heat and power. In the European Pollutant Release and Transfer Register, Sweden and Finland reported 64% and 51% biogenic emissions, respectively, in facilities emitting over 100 kt of carbon dioxide in 2017, while the corresponding collective figure for all European states in the database is 6%. This qualitative study highlights company actors' perspectives on bioenergy with carbon capture and storage within a Nordic regional context and explores their perspective on emerging tensions in the energy transition. Semi-structured interviews were conducted with 20 of the 24 companies with largest point sources of biogenic emissions. The results are framed around four emerging tensions regarding bioenergy with carbon capture and storage from companies' perspectives in this study: (1) absence of reliable long-term policies; (2) limits to companies' climate change responsibility; (3) technical trade-offs of carbon capture; and (4) lack of customer demands for negative emissions. According to most of the companies, it is technically feasible to capture carbon dioxide, but it could be a challenge to determine who is responsible to create a financially viable business case, to enact supporting policies, and to build transport and storage infrastructure. Company representatives argue that they already contribute to a sustainable society, and as such, that bioenergy with carbon capture and storage is not their priority without government collaboration. However, they are willing to contribute more and could have an increasing role towards an energy transition in an international context.

Keywords: Bioenergy with carbon capture and storage; negative emission technologies; energy transition; industry perspectives; Sweden; Finland

Tensions in the energy transition: Swedish and Finnish company perspectives on bioenergy with carbon capture and storage

Emily Rodriguez[a*], Adrian Lefvert[b], Mathias Fridahl[a], Stefan Grönkvist[b], Simon Haikola[c], Anders Hansson[a]

[a] Department of Thematic Studies–Environmental Change, Centre for Climate Science and Policy Research, Linköping University, SE-58183 Linköping, Sweden.

[b] Division of Energy Processes, KTH Royal Institute of Technology, SE-10044 Stockholm, Sweden.

[c] Department of Thematic Studies–Technology and Social Change, Centre for Climate Science and Policy Research, Linköping University, SE-58183 Linköping, Sweden.

*Corresponding author: emily.rodriguez@liu.se

Corresponding author: Emily Rodriguez, emily.rodriguez@liu.se

List of email addresses for all authors:

Emily Rodriguez, emily.rodriguez@liu.se

Adrian Lefvert, alefvert@kth.se

Mathias Fridahl, mathias.fridahl@liu.se

Stefan Grönkvist, stefangr@kth.se

Simon Haikola, simon.haikola@liu.se

Anders Hansson, anders.n.hansson@liu.se

Author contributions

Emily Rodriguez and Adrian Lefvert equally share the responsibility of main author. Emily Rodriguez: Investigation, writing–original draft. Adrian Lefvert: Investigation, writing–original draft. Mathias Fridahl: Supervision, review & editing. Stefan Grönkvist: Supervision, review & editing. Simon Haikola: Supervision, review & editing. Anders Hansson: Supervision, conceptualization, funding acquisition, review & editing.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: