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CO_2 emissions abatement in the Nordic carbon-intensive industry – An end-game in sight?

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ABSTRACT

Analysing different future trajectories of technological developments we assess the prospects for Nordic carbon-intensive industries to significantly reduce direct CO_2 emissions in the period 2010–2050. This analysis covers petroleum refining, integrated iron and steel production, and cement manufacturing in the four largest Nordic countries of Denmark, Finland, Norway, and Sweden. Our results show that the implementation of currently available abatement measures will not be enough to meet the ambitious emissions reduction targets envisaged for the Year 2050. We show how an extensive deployment of CCS (carbon capture and storage) could result in emissions reductions that are in line with such targets. However, large-scale introduction of CCS would come at a significant price in terms of energy use and the associated flows of captured CO_2 would place high requirements on timely planning of infrastructure for the transportation and storage of CO_2. Further the assessment highlights the importance of, especially in the absence of successful deployment of CO_2 capture, encouraging increased use of biomass in the cement and integrated iron and steel industries, and of promoting the utilisation of alternative raw materials in cement manufacturing to complement efforts to improve energy efficiency.

1. Introduction

The reputation, which is partly self-imposed, of the Nordic countries as front-runners in addressing the challenge to mitigate global climate change may be justified but deserves closer critical scrutiny. On the one hand, efficient utilisation of natural and energy resources in the region and pro-active policy interventions have resulted in the decoupling of economic growth from domestic greenhouse gas (GHG) emissions [53,75,98]. On the other hand, the GHG emissions associated with Nordic consumption (accounting for both domestic and international emissions associated with the overall consumption within a country) continue to increase [18,96]. Of greater relevance to the present study, when it comes to the 'high-hanging fruits' (e.g., decarbonising the transport and industry sectors), the Nordic countries face the same challenges as most of the other countries in the EU – and around the world.

All Nordic countries have presented long-term visions for large reductions in GHG emissions up to Year 2050. Achieving these goals would entail a drastic deviation from the historical trend and would require profound changes across all sectors of the Nordic economies. While there is evidence that the determination to sustain the competitiveness of domestic industry will continue to limit the room for manoeuvring for climate policy that targets the industrial sectors, both nationally and regionally, there is a clear desire among Nordic legislators to identify and enforce strategies that would enable and facilitate decarbonisation [78,82,95,111,113]. Several studies have explored how such a transition could be realised on a national level in: Denmark (e.g., [61,63–66,90]); Finland (e.g., [50,51,82,122]); Norway (e.g., [68,77]); and Sweden (e.g., [47,49]), and on the Nordic regional scale (e.g., [6,74]). While the sectoral coverage and the methodological approaches of these studies vary, the treatment of the Nordic industry sector is often crude. Yet, the Nordic countries are highly industrialised and hold many energy and carbon intensive industries, which are linked to domestic natural resources (e.g. iron and steel, oil and gas and cement) and/or rely on the burning of fossil fuels (iron and steel and cement). Thus, there is a need to assess how such industries can be transformed to comply with the Nordic long-term visions for large reductions in GHG emissions up to Year 2050.

This study covers three carbon-intensive industry sectors, petroleum refining, integrated iron and steel production, and cement manufacturing in the four largest Nordic countries of Denmark,

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Finland, Norway, and Sweden (i.e. Island not included). In Year 2010, total emissions from the 23 industrial plants covered within the scope of the study amounted to 25 $MtCO_2$ as shown in Table 1 [15,25]. This corresponds to approximately 10% of the total CO_2 emissions in the Nordic region. Carbon-intensive industry accounts for approximately 20% of the total CO_2 emissions in Finland and Sweden, the corresponding shares in Denmark and Norway are considerably lower at 6–7%.

Several studies have assessed the potential for future CO_2 emission reductions for global industry, as well as for the industrial sectors of selected regions and countries (e.g., [16,54,94,117]). Similarly, previous studies by the authors have explored the prospects for presently available abatement technologies [92] and CCS [93] to achieve significant reductions in CO_2 emissions from carbon-intensive industries in the EU (EU-27). As Nordic legislators have gradually intensified efforts to identify workable long-term climate policy strategies, studies are increasingly focussing on the role of domestic industry in the process of decarbonising the Nordic economies (e.g., [53,97,110,127,128]). However, there is a scarcity of studies that account specifically for the technological heterogeneity of the energy-intensive process industry, and that in comprehensive and transparent ways, explore the potential of each industrial sector to meet stringent CO_2 reduction targets in the long term. By placing emphasis on the technological feasibility of achieving significant reductions in CO_2 emissions from Nordic carbon-intensive industry the present work contributes to defining the scope of action for Nordic climate policy. To assess the more radical system changes necessary to reach almost zero CO_2 emissions our approach has been to combine the traits of both bottom-up type studies (technology explicitness) and top-down type studies (capturing economy wide trends) in one accounting framework (as discussed in e.g. Refs. [2,48,109]). This by accounting for the technological heterogeneity within and between the studied sectors, while also, considering wider trends relevant to future CO_2 emissions in each industry. Given the time horizon chosen for the study (2010–2050), the future trajectory of technological developments is obviously associated with significant levels of uncertainty. To illustrate and analyse how different strategic choices influence the prospects for achieving the long-term goals of CO_2 emissions reduction in the Nordic carbon-intensive industry, we have used an exploratory scenario analysis, as described by Refs. [9,119]. The aims were to: (i) investigate the prospects for further CO_2 emissions reduction within current production processes; (ii) assess the extent to which the implementation of CO_2 capture in industrial settings might contribute to reducing CO_2 emissions; and (iii) evaluate the effects and policy implications of different future trajectories of technological developments for the Nordic carbon-intensive industry.

2. Methods

2.1. Data collection

A key component of the analysis is the provision of a good representation of the energy, material, and CO_2 flows at each of the industry plants included in the study. For this purpose, the Chalmers Industry Database [91–93] has been updated and used. Table 2 outlines the main components of the database for the four countries in focus in the present study, and presents the data sources used to update the database so as to meet the requirements of the present study and ensure the quality of the data. The database has been further complemented and validated with statistics

Table 1
Characteristics of the industries covered in the analysis.

	Number of installations	Capacity	Average annual CO_2 emissions (2008–2012)	Average annual allocations of emissions allowances[a]	
				2008–2012	2013–2020
		Mt crude oil/year	$MtCO_2$/year	Million EUA/year	Million EUA/year
Petroleum refining					
Denmark	2	8.7	0.9	0.9	0.8
Finland	2	13.0	3.3	3.2	2.3
Norway	2	15.9	1.9	1.9	1.5
Sweden[b]	5	21.8	3.0	3.2	2.6
Total	*11*	*59.3*	*9.1*	*9.2*	*7.3*
		Mt crude steel/year	$MtCO_2$/year	Million EUA/year	Million EUA/year
Integrated iron and steel					
Finland[c]	2	3.5	4.6	5.7	4.5
Sweden[d]	2	4.1	5.0	7.0	4.8
Total	*4*	*7.6*	*9.6*	*12.7*	*9.4*
		Mt cement/year	$MtCO_2$/year	Million EUA/year	Million EUA/year
Cement manufacturing					
Denmark	1	3.0	1.7	2.6	1.9
Finland	2	1.5	0.8	1.2	0.9
Norway	2	1.9	1.2	1.3	1.0
Sweden	3	3.0	2.2	2.2	1.7
Total	*8*	*9.4*	*5.8*	*7.5*	*5.6*

[a] EU allowance (EUA) refers to the carbon credits traded under the EU Emissions Trading System (EU ETS). One EUA represents one tonne of CO_2 that the holder is allowed to emit. All of the industries assessed here belong to the industrial sectors deemed to be exposed to a significant risk of carbon leakage under the EU ETS.

[b] The two Swedish 'specialty refineries' are not included in the analysis.

[c] The smallest of the two Finnish integrated steel plants, Koverhar Steel Works, has been mothballed since 2012. With the exception of the sintering plant (closed in 2011) the Raahe steel plant is fully integrated with coke ovens, blast furnaces, steel plant, rolling mills and power plant ([87,88]). As of 29 July 2014 Rautaruukki is part of SSAB.

[d] The reported emissions include CO_2 emissions that result from the combustion of energy gases sold by SSAB to Lulekraft AB. With the exception of the sintering plant the Oxelösund plant includes the entire production line stretching from raw materials to rolled plate. The Luleå plant, have neither sintering plant nor rolling mill, steel slabs is the final product.