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Full **Length Article**

Perceptions of decarbonisation challenges for the process industry in Sweden and Norway

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ABSTRACT

The energy-intensive process industries (EPIs) account for a high share of global carbon emissions but have so far been slow to decarbonise. One of the reasons for the slow pace is that central problems and solutions are contested among stakeholders. To develop effective and inclusive transition policy, a better understanding of different perspectives on decarbonisation challenges is needed. In this paper, we use Q methodology to address this gap with an analysis of EPI decarbonisation in Sweden and Norway. The research draws on 50 interviews where different types of stakeholders sorted and reflected upon statements that describe potential decarbonisation challenges. Through factor analysis, we identify four salient narratives in each country, which emphasise different problems and trade-offs. However, we also find similarities across the narratives, both within and across countries. A key challenge that is emphasized in both countries is to ensure a sufficient supply of electricity at competitive prices. Ultimately, we demonstrate how these findings are important for providing policy recommendations.

1. Introduction

The energy-intensive process industries (EPIs) account for approximately 25 % of global energy-related greenhouse gas emissions and are off track to align with the Net Zero Emissions by 2050 Scenario promoted by the International Energy Agency [1]. Despite incremental advances in renewable energy and energy efficiency, progress is “far too slow” (ibid.), necessitating “herculean efforts” [2: 1270] for decarbonisation. In fact, carbon intensity improvements have stagnated the last 30 years, while EPI emissions have risen faster since 2000 than any other sector [3]. Moreover, emissions stem not only from energy use, but also industrial processes themselves [1,4]. For instance, steel and cement production give rise to large emissions, avoidable only through radical innovation that goes far beyond renewable energy and energy efficiency measures [5,6].

However, the modus operandi of EPI firms stands in stark contrast to the urgent need for transformative change. Competing in global markets with largely undifferentiated products, these firms rely on continuous production and mainly incremental improvements to stay competitive. In addition, long investment cycles, large-scale physical infrastructure, and high investment costs create substantial barriers for new entrants [4,7]. Additional challenges arise from the necessity of change in multiple adjacent sectors, both upstream and downstream. This includes the expansion of various input factors such as electricity (including grid capacity), hydrogen and/or biomass, the realization of circular value chains, or entirely new infrastructures such as for carbon capture, storage and utilization (CCUS). This implies a need for transformative change both in EPIs and other sectors, involving both established and emerging technologies, infrastructures and interfaces [5,8,9,10].

Decarbonizing EPIs is thus inherently complex and constitutes a

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significant policy challenge [11]. The more technically focused scientific literature has increasingly examined the various decarbonisation options available for EPIs, while research on industrial decarbonization from a socio-technical perspective highlights the critical need for innovative technologies and robust policy frameworks to achieve deep decarbonization across EPIs. For example, Nurdiawati and Urban [12] review current technologies and policies aimed at reducing EPI emissions, emphasizing the importance of a multi-faceted approach. Sovacool et al. [5] propose 'bold steps' toward net-zero industry, underscoring the need for systemic change across sociotechnical systems. Sector-specific studies, such as those by Griffiths et al. [13] and Karakaya et al. [6], explore decarbonization pathways for the cement, steel, and chemical industries, offering insights into the necessary technological innovations and policy options.

It has also been highlighted, but not thoroughly investigated, that unresolved contestation related to problems and solutions can lead to ineffective policies [8,14]. This underscores the importance of understanding the characteristics of underlying viewpoints among industrial firms and other stakeholders with an interest in stimulating and shaping EPI decarbonisation. A key premise for this paper is accordingly that the absence of aligned perceptions of challenges may be detrimental to the transition if they remain unresolved [15].

Against this background, this paper contributes to the existing literature by employing a discursive Q research design [16] to analyse and compare how different actors in Sweden and Norway perceive challenges in the decarbonization of EPIs. Both countries have ambitious climate goals, similar policy systems and EPIs with large emissions, but differ with respect to EPI structure, national resource endowments, and climate policy priority settings and instruments [17–20], making them highly interesting for comparison. A key aim of the analysis is to see whether actors have aligned or misaligned views on EPI decarbonisation challenges, and to illuminate dimensions of contestation that may lead to backlash or resistance in policy, industry, or society. Empirically, the paper draws on a unique dataset of 25 standardized interviews per country. Following Q methodology [16,21], study participants sorted 56 statements about potential challenges for EPI decarbonisation according to their perceived importance. The analysis yielded four distinct narratives in each country, which differ with regards to perceptions of technological solutions, problems in the innovation process, and government policy, while reflecting underlying views concerning trade-offs between decarbonisation and other societal objectives. However, we also identified similarities across the narratives, both within and across the two countries. Overall, the main challenges that are shared across the two countries are scarcities in renewable energy, grid capacity and circular resource flows, as well as uncertainties related to competitiveness and geopolitical instability. We also found differences across the countries, of which one notable discrepancy pertains to whether EPI decarbonisation targets are considered achievable.

Following this introduction, we describe the empirical background and context of our study in Section 2, followed by an outline of our research design in Section 3. In Section 4, we present our results, considering differences and similarities between the narratives, both within and across the two countries. Lastly, in Section 5, we discuss our findings and highlight conclusions and policy implications.

2. Decarbonisation in the Norwegian and Swedish process industries

EPIs produce various products that are crucial for society, but also leave a substantial carbon footprint. In 2020, EPIs accounted for approximately 23 % of all direct emissions, nearly 40 % of total final energy consumption, and if indirect emissions (i.e., from industrial power and heat demand) are considered, they were responsible for nearly 40 % of global emissions [22]. Approximately 70 % of the emissions are concentrated to cement (28 %), iron and steel (28 %) and chemicals (15 %) [22]. However, what is particularly troublesome for the future is that advanced economies currently use up to 20 times more plastic and 10 times more fertilizer per capita than developing economies [23], and global demand for cement is expected to increase 12–23 % by 2050 [24].

The main EPI emissions stem from combustion of fossil fuels in the production of plastics, cement, aluminium and steel [25]. But almost one-quarter are process emissions that result from chemical or physical reactions (e.g. 65 % of emissions from cement production), and these cannot be avoided by switching to alternative energy sources. Moreover, since some industrial processes require temperatures as high as 1600 °Celsius, switching from fossil to alternative fuels can be costly and technically challenging, yet is not a mission impossible [3,11,25].

The technological solutions for decarbonising EPIs include electrification, changing raw material feedstocks, hydrogen, and carbon capture utilization and storage (CCU/CCS/CCUS). Table A.6 provides an overview of main decarbonisation pathways explored in a Nordic and European context. To what extent these are relevant and feasible varies across specific industries, countries/regions and individual plants, depending on various factors [28] beyond the scope of this paper.

2.1. Sweden

Over time, Sweden has reduced its total domestic emissions at a faster pace than its industrial emissions (Fig. 1), which reached a record high share of 33 % of domestic emissions in 2022 [17]. Nevertheless, industrial emissions have been reduced with 26 % since 1990. This reflects significant efforts to curb industrial dependency on fossil fuels, which peaked at 60 % of total energy use in the early 1970s and has since been reduced to 23 % [29]. Given the successful phase-out of fossil fuels from many Swedish EPIs, it is not surprising that current emissions are dominated by industries with large process emissions. In 2022, the iron and steel industry accounted for 12.6 % of total domestic emissions, followed by refineries at 6.0 % and cement production at 5.9 %. Notably, emissions from these industries are concentrated to a few and very large-scale production facilities.

The non-fossil energy used in Swedish industry is carried by biomass and electricity [28]. Industrial electricity consumption was 45 TWh in 2022, representing approximately 25 % of Sweden's total electricity production (170 TWh) and 33 % of the total electricity use (134 TWh) [29]. Total electricity demand is expected to double by 2045 as industries replace thermochemical processes with electricity, but also following a general trend of electrification in society [30]. Sweden's electricity mix primarily consists of renewable energy (61 %), nuclear power (27 %) and biomass and waste incineration (16 %) [29]. Industrial emissions are thus primarily Scope 1 and electricity consumption only contributes approximately 8 % to total domestic emissions [31], which is relatively little compared to other EU countries (but considerably more than in Norway). Sweden has also been a net exporter of electricity since 2011 and exported approximately 20 % of its total production in 2022 [29].

The extensive use of biomass, particularly forest residues, in Swedish EPIs that produce pulp, paper, heat and power not only results in lower fossil emissions, but also gives to large biogenic emissions [29]. These are accounted for in the land-use sector (LULUCF) rather than industry [32], but are nevertheless relevant for the decarbonization of EPIs, since they can be used to produce negative emissions with bio-CCUS

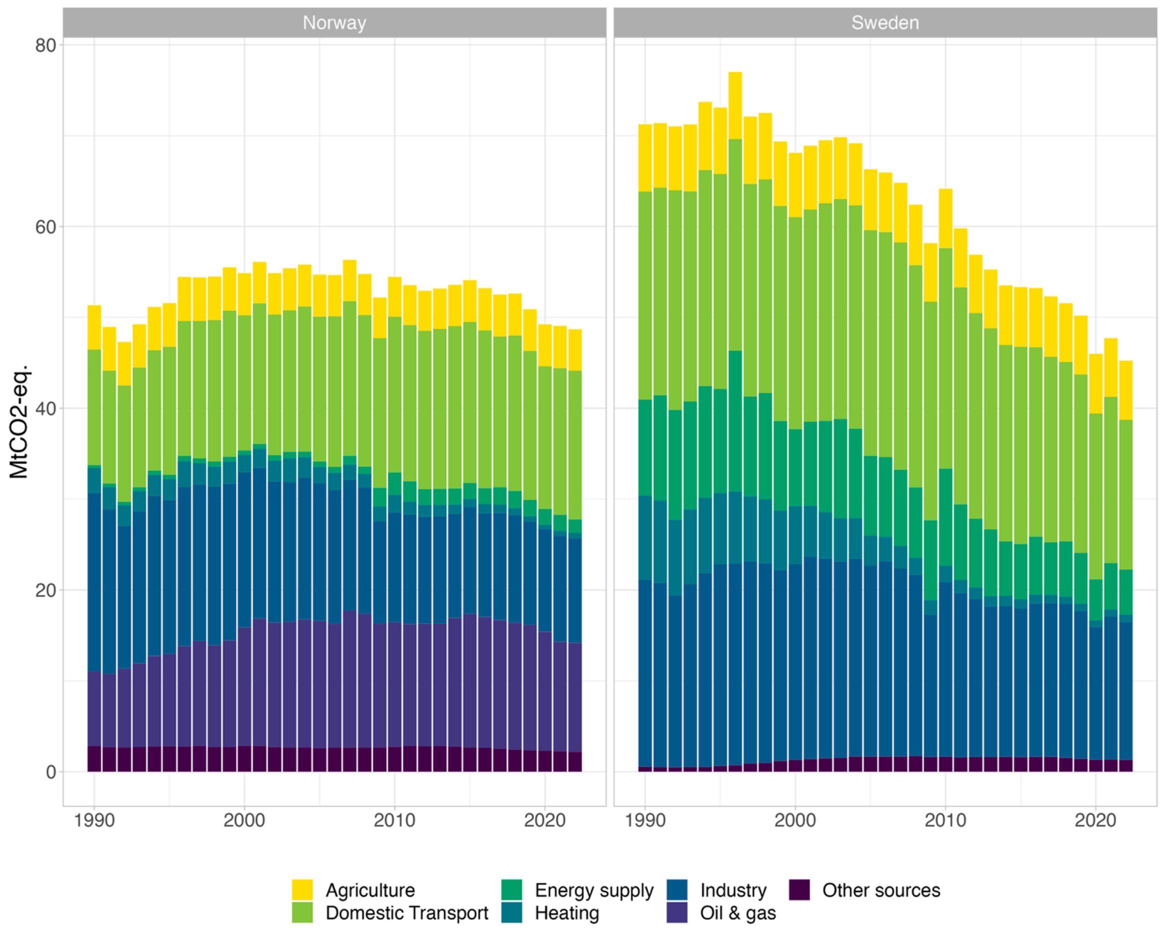

Fig. 1. Greenhouse gas emissions by sector in Norway and Sweden. Sources: Naturvårdsverket [17,26], SSB [27].

technology. In turn, negative emissions may be sold on emerging private markets and be used to meet national and international climate policy obligations [33]. However, there are no immediate possibilities to store captured carbon in Sweden. The diffusion of bio-CCS technology thus hinges on the development of international value chains. Swedish policymakers and industrial firms therefore strive to establish collaborations with storage projects in countries such as Norway and Denmark [34].

Since 2016, the Swedish climate law [35] stipulates that Sweden shall reach net-zero emissions by 2045 and negative emissions thereafter. The national climate policy framework also obliges the Swedish government to submit a climate action plan for achieving the net-zero target every fourth year. The plan is evaluated by an independent national climate policy council, which has critiqued current efforts regarding both industrial and overall emissions [36].

Nevertheless, the Swedish climate law has broad support among policymakers and various national-level policy instruments complement European climate policies (e.g., EU-ETS, Fit-for-55). Most importantly, Sweden has since 2018 had a long-term scheme in place to support research, development, demonstration, and investment in low-carbon industrial solutions [19]. The government also offers green credit guarantees and is considering targeted support for operating bio-CCS plants via reversed auctioning of negative emissions [33]. In addition, national policymakers have taken an active role in initiating and facilitating dialogues among firms and other actors in different sectors via the initiative "Fossil Free Sweden" [37]. This has resulted in several interrelated and broadly supported roadmaps towards net-zero emissions.

In the end, most Swedish EPIs with large emissions aim to decarbonise in an even shorter timeframe than what the national climate goals demand [38]. They also exhibit extensive participation in publicly funded innovation projects oriented towards decarbonisation, where research, development and demonstration activities revolve around technological trajectories that are seen as viable routes to net zero emissions, such as hydrogen-based steel production and cement production with CCS [39].

2.2. Norway

While total domestic emissions in Norway have only been reduced marginally since 1990, Norwegian EPIs have reduced their emissions by 43 % since 1990 (Fig. 1). Industrial emissions now constitute approximately 25 % of total emissions, most of which are Scope 1 emissions from the production process itself or process-related use of energy and fuels [18,40].

The main product groups are aluminium, ferrosilicon, chemicals (mainly petrochemicals), minerals (e.g., cement), fertilizers, and pulp and paper (Fig. 2). The process industry consumes around a third of Norway's total electricity production, but because of the high shares of renewables in the Norwegian electricity mix, Scope 2 emissions are very low [41]. As in Sweden, a substantial part of EPI emissions stem from a few large plants that rely on (conventional) process technologies that

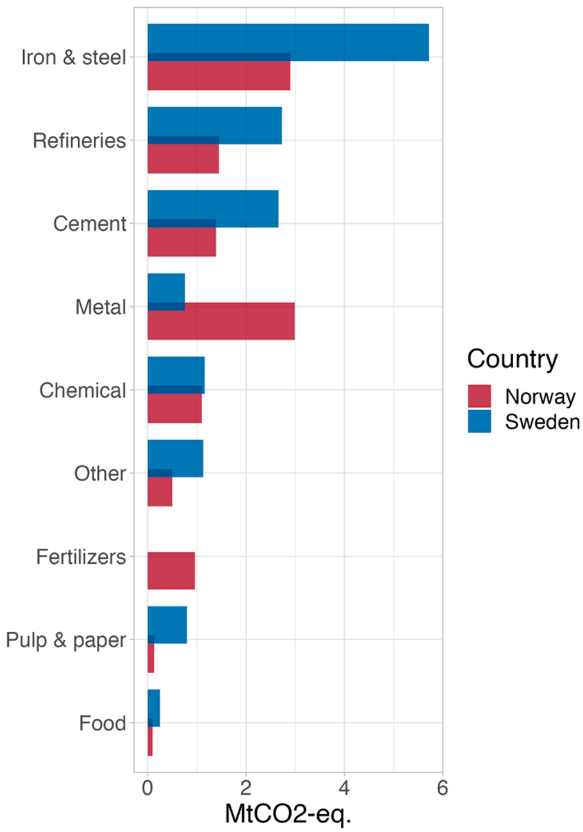

Fig. 2. Process industry greenhouse gas emissions in Norway and Sweden. Sources: Naturvårdsverket [17,26], SSB [27].

cannot easily be substituted.

Norway is an energy-rich nation, both in fossil fuels and renewables. The discovery of petroleum resources in the late 1960s laid the basis for petrochemical and refining activities, whereas other EPI activities have been especially reliant on access to electricity. For decades, Norway has been a net exporter of electricity, but this is expected to change in coming years due to rapidly increasing demand for renewable power, both for new industries (e.g. hydrogen production) and the decarbonisation of existing industries via electrification, both in the onshore EPIs as well as offshore petroleum activities [42].

The Norwegian climate policy framework is formalized in a "climate law" [20] stating that GHG emissions need to be reduced by 50–55 % from 1990 levels by 2030, and for Norway to be a "low-emission society" by 2050. The national "climate plan" [20] outlines how this should be achieved, providing guidelines for decarbonisation of all sectors, including those that are part of the European emissions trading scheme (ETS) as well as those that are not. Prosess21, a public-private forum established by the state in 2018, has been an important provider of strategic advice and recommendations to policy makers [40]. This forum is comprised of industry actors, public authorities, RDI financiers, interest groups and research organizations, and has been organized around 10 expert groups that have focused on various topics including new product areas, competence needs, global competition, and CCS.

Similar to Sweden, the Norwegian EPI is thus covered by ETS, which is seen as a key mechanism for achieving decarbonisation [43]. More generally, the climate plan outlines three central policy pillars: carbon pricing, compensation for increased power prices, and research, development and innovation (RDI) funding. CCS is also an important solution that is heavily supported by the Norwegian state, both through funding to various research (including a dedicated CCS testing facility since 2012), and the large-scale storage project Longship on the Norwegian continental shelf that is currently being developed [44,45].

Electricity-intensive industries are compensated by the state to meet the growing energy price caused by the EU ETS mechanism, with an aim of avoiding industry offshoring. Participation in the ETS moreover means that the process industry is eligible for financing from the EU Innovation Fund. Public RDI funding, for instance through the 'Green Platform' scheme, 'Centres for Environment-friendly Energy Research', play an important role in developing new solutions to industry decarbonisation and create economic opportunities for Norwegian firms.

2.3. Similarities and differences

Sweden and Norway are both small, open and export-oriented economies with relatively large EPIs, which historically developed based on energy resources (especially hydropower) and raw materials such as iron ore and timber. Both countries have ambitious climate goals, albeit with Sweden having a clearer, broadly supported and more ambitious target for EPI decarbonisation. The share of fossil energy in the electricity mix is very low, with hydro and wind power dominating in Norway while Sweden has a large share of hydro, nuclear and wind as well as some combined heat and power production from waste and biofuels [46]. An additional common feature is that the potential for large-scale new hydropower projects is constrained, leaving wind power the main technology that can add substantial new renewable power production capacity in the short term [42,47]. However, the expansion of low-carbon electricity production is contested in both countries. This especially concerns wind power, where new licenses have been halted completely in Norway and constrained in Sweden in recent years following public and political opposition [48,49].

At the same time, there are differences that are likely to influence how EPI decarbonisation challenges are perceived. To begin with, the countries' EPIs differ in composition. Sweden has a large iron and steel industry, and a substantial pulp and paper industry with large biogenic emissions. In Norway, lightweight metals (e.g., aluminium) and ferrosilica are more prominent. Norway is also a large oil and gas (O&G) producer with considerable emissions from extraction, processing and refining, while Sweden has three main oil refineries that give rise to substantial emissions but no significant domestic O&G resources. In addition, Norway has domestic offshore carbon storage opportunities and has employed CCS in the O&G sector since the mid-1990s. Offshore carbon storage is now offered to other sectors both domestically and internationally. This implies a potential complementarity whereby Sweden's large biogenic emissions can be stored in Norway, thus generating negative emissions. Sweden also has a much more substantial manufacturing industry, with many large firms that consume EPI products. Furthermore, several EPIs in Sweden to larger extent use domestic raw material inputs (notably iron ore, lime and timber), whereas Norway's EPIs rely more on the import of raw material inputs (e.g., bauxite for aluminium production). It is important to note that only the onshore petroleum processing units (similar to refineries in Sweden) are considered part of the EPIs. Some of these petroleum processing plants, such as Mongstad oil refinery and Snøhvit LNG plant, are among the very largest emission points in Norway. The bulk of GHG emissions from the O&G sector in Norway are from offshore activities. However, two things are important to take note of. In total, emissions from O&G and EPIs account for 25 % each of Norway's emissions [50]. However, whereas EPIs have reduced emissions with 43 % from 1990 to 2023, emissions from O&G increased by 40 % in the same time period, yet they have been relatively stable or slightly declining since the early 2000s [18,51].

Emission reductions in both sectors is paramount for Norway to reach its climate targets, and in this context the two sectors compete over scare resources, notably electricity from renewable sources [42].

3. Research design

Data collection for this paper was based on Q methodology, which is used to study human subjectivity in relation to a wide variety of topics [16,21,52], with the aim to identify views or perceptions held by groups of participants [see for example [53,54]. Data is collected through standardized interviews where a purposively sampled set of participants (the p-sample) sort pre-defined statements (the q-sample).

In both countries, the p-sample (see Table A.1) was designed to include individuals representing different perspectives while being knowledgeable about the EPIs. Participants were identified through media, parallel studies of decarbonization networks and technologies in both Norway and Sweden, and snowballing whereby participants in early interviews suggested other potential participants. The final p-samples include representatives from different types of organizations, roles within organizations, industry sectors, engagement levels (i.e., firms with differing levels of investment in decarbonization projects) and political viewpoints (i.e., labor unions, trade organizations and environmental NGOs).

The q-sample was designed to capture a representative sample of potential challenges in the decarbonisation of Swedish and Norwegian EPIs. Statements were developed both inductively and deductively. As a first step, expert interviews, document analysis (e.g., media, industry reports and roadmaps) and scientific literature were used to compile a gross list of over 200 statements that covered a wide range of viewpoints. Overlapping viewpoints were then merged and reformulated, to arrive at a final q-sample with 56 statements (see Table 1) related to themes such as technology, policy, infrastructure, resources, finance and demand. The final q-sample was then discussed with a broader group of colleagues whereupon some statements were slightly reformulated for clarity.

Interviews were performed with the Q Method Software[1] tool, which provides an online interface where participants sort statements as well as software for statistical analysis of generated data. The online interface was used in combination with video conference, enabling (technical) guidance during the sorting procedure as well as the opportunity to pose open questions based on an interview guide. Throughout the interviews, participants were encouraged to offer their personal opinions, rather than the official positions of the organizations they represent. Note also that study participants were asked to consider the entire EPIs rather than segments such as cement or pulp and paper. Each interview followed four steps, all of which were recorded:

1. A brief introduction to the research project, the purpose of data collection, and an assurance of anonymity. In this step informants were also asked about their background and current position.
2. A pre-sorting of statements into three categories: 'Less important', 'Quite important' and 'Very important'. This was done to simplify the detailed main sorting in the next step. However, statements that were pre-sorted as being very important could still end up at the other end of the scale in the main sorting.
3. A main sorting (or ranking) of statements on a scale from 'Less important' (−5) to 'Very important' (+5) according to a forced distribution matrix (see Fig. 3). This was the most time-consuming part of interview, and typically involved considerable re-organizing as participants needed to prioritize, especially what they considered to be most and least important.
4. Open questions focused on the rationale behind the main sorting and participants' views on action required to address key challenges. Participants elaborated mainly on the statements that ended up at the extreme ends of the distribution matrix.

The analysis unfolded in three steps. First, we analysed correlations among the data sets generated in each interview.[2] This enabled the extraction, evaluation and characterization of factors that represent typical narratives that are, to varying degree, shared by the participants. Based on commonly used significance criteria (i.e., the Kaiser-Guttman criterion [56,57], see Tables A.2/A.3), four factors were extracted for each country (SE1-SE4 and NO1-NO4). These factors together account for 41 % (Sweden) and 36 % (Norway) of the study variance, which is in line with what can be expected in a Q study [16]. After factor rotation through the Varimax method, 21 of the Q sorts load significantly on one of the factors in the Swedish analysis, while 20 of the Q sorts load significantly on one of the factors in the Norwegian case (see Tables A.2/A.3/A.4). The remaining Q sorts do not load significantly on any of the factors and accordingly represent deviating perspectives. To uncover and formulate the narratives represented by each factor, its quantitative characterization (i.e., statement rankings were interpreted using qualitative data (notably participants' explanation of their statement ranking) from the interviews [16]. Although the procedure accounted for all statement rankings associated with each factor, particular attention was given to salient statements (i.e., top/bottom ranked statements and statements ranked (much) higher/lower than all other factors (Table 1)). To avoid cross-country influences in data interpretation, the challenge narratives for Sweden and Norway were developed through insulated analytical procedures. All authors were subsequently involved in the cross-case comparison of narratives within and across the two countries.

Second, we compare the ranking of statements within the identified narratives between narratives and across countries, supported by consideration of consensus statements (i.e., statements that are ranked similarly by factors within each country). This allowed us to identify statements that, at a more aggregate level, were sorted in similar or different ways in the two countries. Using data from Q interviews in this manner should not be conflated with the factor analytical procedure which underlies the identification and formulation of narratives. However, it brings valuable complementary insights on how national-level contextual differences may influence how problems and solutions to EPI decarbonisation are perceived.

Third, and lastly, we used qualitative data from the interviews when discussing and identifying the implications of our analysis. The participants' responses to open questions, as well as their motivation of statement rankings, thus constitute a supplementary source of insight that complements the identified challenge narratives and their similarities and differences. In interpreting our results, we also draw on secondary material (media, reports, government documents, research etc.) generated in the same period.

4. Results and analysis

Four distinct challenge narratives were identified in both countries. We first present these briefly for each country, and thereafter analyse aggregate statement rankings across the cases and highlight areas of agreement and disagreement. When presenting the narratives, we provide reference to rankings of salient statements (Table 1) and individual participants (Table A.1) and their factor loadings (Table A.4).

[1] https://qmethodsoftware.com/

[2] Note that the analysis of data from the interviews performed in Sweden is also presented as part of a related but different research article [55].However, the analysis of data from the interviews performed in Norway, as well as the cross-country comparison, are unique for this paper.

Table 1
Ranking of statements across all four factors in each country (NO1–4; SE1–4) on scale +5 (dark green) to −5 (dark red). Statement listing order by average across all eight factors.

S.ID	Statements	NO1	NO2	NO3	NO4	SE1	SE2	SE3	SE4
S41	The climate transition requires large amounts of electricity with competitive pricing	5	4	4	5	5	5	5	**4**
S44	The expansion of the electricity grid is too slow	2	3	4	5	5	4	3	**0**
S54	The climate transition is progressing too slowly in the process industry	3	*5*	**1**	3	*4*	**0**	3	3
S34	There is a lack of a global price on carbon emissions	5	3	5	-1	*4*	3	1	1
S32	There is a lack of political direction, overview and coordination	3	2	3	*4*	2	**-2**	*4*	1
S55	Geopolitical instability and ongoing war in Europe reduce the outlook for the climate transition	3	1	*5*	2	**-1**	3	0	3
S42	There is a lack of circular flows that give the process industry access to recycled raw material	1	1	1	2	3	**0**	4	4
S09	Too little effort is made to reduce the need for virgin materials (i.e. reuse and reduced consumption)	**0**	1	*2*	1	2	2	4	4
S07	The process industry supplies a global and highly competitive market	*3*	**1**	2	2	**0**	1	*2*	1
S36	The environmental permitting process is too slow	2	*4*	**-3**	0	0	5	5	**-1**
S30	Visions, strategies and plans within the climate transition do not lead to concrete activity	2	3	3	3	*3*	-5	-1	1
S53	The political debate about the future energy mix hinders increased electricity production in SE/NO	*4*	2	0	0	*3*	0	2	**-2**
S46	There is a lack of infrastructure for carbon transport and storage	4	**2**	**-1**	4	0	*3*	0	**-4**
S04	Capital intensive production with long investment cycles creates a lock-in to old technology	1	0	0	1	3	0	0	3
S25	The climate transition is in conflict with other environmental goals (e.g. biodiversity)	-2	-1	2	*4*	**-2**	0	1	5
S33	Climate demands are too low in public procurement processes	**-1**	2	1	2	0	**-2**	2	2
S35	There is a lack of long-term policy instruments at the EU level (i.e. emissions allowances, carbon tolls, investment programs)	1	1	**-1**	0	*3*	1	1	**0**
S51	Key technologies are immature	1	5	**-1**	1	**-2**	*2*	0	-1
S16	It is difficult to recruit the right competence	1	*3*	-5	1	*4*	1	1	**-1**
S31	Climate investments are driven by the current societal discourse, rather than long-term analyses	1	**-3**	2	1	1	1	**-1**	*2*
S15	There is too little experimentation with new solutions	0	1	1	**-1**	*2*	**-3**	1	1
S26	The climate transition leads to materials and fuels with higher prices	*2*	**-2**	0	-1	**-1**	2	0	2
S29	Climate change is not taken seriously enough	0	**-2**	1	*3*	1	-5	*2*	1
S43	The possibility of increasing the production of biomass from SE/NO forests is contested	-2	*0*	**-3**	-1	2	1	1	*3*
S39	Public support to research and development of new technology is insufficient	*2*	1	0	0	-2	-1	*3*	**-3**
S18	Knowledge about new business models is lacking	0	**-2**	1	1	*1*	**-1**	0	0
S28	The climate transition leads to more expensive products that are not demanded by consumers	*4*	**-1**	3	0	-2	**-4**	-2	*1*
S52	It is difficult to understand the consequences of new technologies	-1	0	*1*	-1	-1	*3*	**-2**	0
S38	Government investments and credit guarantees are insufficient	2	1	**-4**	2	-2	-2	*2*	-1
S45	The supply of important components in new technology is uncertain	-1	0	**-2**	*2*	-1	*2*	-1	-1
S37	The environmental permitting process does not account sufficiently for climate goals	-1	0	-2	-2	1	0	*3*	**-1**
S01	Climate demands on the capital market are too low	-3	-3	-1	*1*	2	**-1**	1	2
S10	There is an excessive belief in the potential to reduce climate impacts through increased use of biomass	-4	3	3	-4	-3	2	-3	2
S03	Incumbent actors focus on energy and materials efficiency rather than far-reaching system transformation	-2	*2*	-2	-2	-1	-1	-1	*3*
S08	The climate impact of non-fossil emissions receives too little attention	-2	-3	-3	*3*	**-3**	1	0	*2*
S49	There is a lack of collaboration among public and private actors	-1	-1	-5	*0*	1	**-1**	*2*	0
S27	There is no demand for materials and fuels with low climate impact among the process industry's customers	*3*	-1	0	**-2**	*1*	-3	-1	-3
S02	Financial actors are not willing to make high risk investments	-1	-1	**-4**	*1*	1	-1	1	**-2**
S13	The climate transition is oriented towards too few technological alternatives	0	0	-1	-1	-1	*1*	-2	**-3**
S14	There is an excessive belief in the potential to reduce climate impacts through increased use of hydrogen	-5	*4*	1	**-3**	-3	*4*	-2	-3
S56	There is a lack of visionary leadership	-3	**-4**	-2	*3*	*2*	**-4**	0	0
S11	There is an excessive belief in the potential to reduce climate impacts through CCS/CCU technology	-5	*2*	0	-4	0	-1	**-2**	*1*
S21	Reaching zero emissions until 2045/2050 is not a realistic goal	0	0	*4*	-5	-4	*2*	-5	-2
S22	The goal's focus on national emissions hinders SE/NO companies to create global climate benefits	1	**-4**	*2*	-2	-3	*4*	-4	-5
S24	The climate transition threatens local ecosystems and cultural values	-1	-5	0	0	**-4**	-3	-3	5
S05	It is difficult for new actors to enter the process industry	**-4**	0	0	-3	0	0	-1	**-3**
S06	Incumbent actors have insufficient capabilities to innovative	-3	-3	-1	-1	0	**-2**	-1	0
S20	Swedish universities and research institutes fail to support the process industry with technical knowledge	*0*	-1	-2	-5	-1	*3*	**-3**	-2
S48	There is a lack of collaboration among SE/NO and international actors	-3	-2	-3	*-1*	*1*	0	**-3**	-2
S17	It is difficult to assess emissions reductions from new solutions	**-3**	-1	-1	0	-3	*1*	-3	**-4**
S12	There is an excessive belief in the potential to reduce climate impacts through electrification	**-4**	-1	*3*	-3	-4	-1	-4	-1
S40	Too little support is given to SE/NO firms and stakeholder groups that may be disadvantaged by the climate transition.	*1*	-5	-2	-3	-5	-2	*3*	-2
S47	It is difficult to establish partnerships among industrial companies, suppliers and customers	*0*	-2	-1	-2	*-1*	-2	-4	-4
S19	Knowledge from research and development projects is not diffused among actors in the climate transitions	*-1*	-2	-3	**-4**	*0*	**-4**	-2	-1
S50	Important actors such as customers, suppliers and specialists are missing in innovation projects	-2	-3	**-4**	-2	-2	**-3**	-1	*0*
S23	The climate transition will harm Swedish/Norwegian exports	-2	**-4**	*2*	-3	-5	*-3*	-5	-5

*Note: Italics = Statement ranked higher than in all other factors in the country, Bold = Statement ranked lower than in all other factors in the country, Underlined = Statement ranked much (two orders) higher/lower than in all other factors in the country.

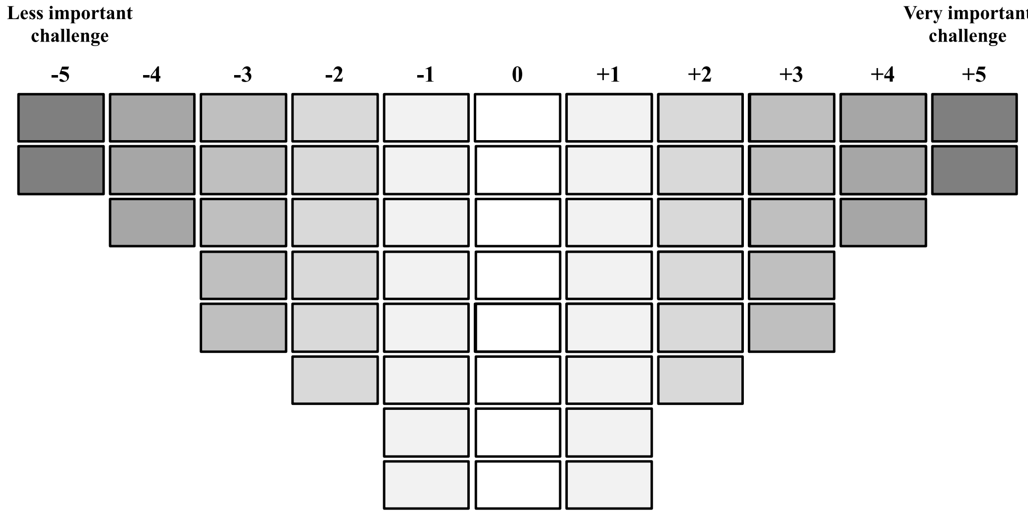

Fig. 3. Statement ranking matrix.

4.1. Sweden

4.1.1. Challenge narratives

The first Swedish narrative (SE1) *emphasizes weak networks and collaboration*. While it expresses optimism about achieving zero emissions through new production technologies (S21, −4; S12, −4; S10, −3; S51, −2), which could provide competitive advantages for domestic firms (S23, −5; S40, −5), the focus is on challenges such as inadequate infrastructure and weak collaboration among industry, policymakers, customers, investors, and universities. The electricity system is considered inadequate (S44, +5; S41, +5), and there is a lack of circular flows for renewable feedstock (S42, +3). The narrative emphasizes the need for clearer policy incentives and "rules of the game" (S34, +4), urging policymakers to take a more active role in guiding and coordinating efforts (S32, +2; S35, +3; S56, +3). Poor links between universities and industry (S16, +4; S18, +1) and a lack of progressiveness among customers and investors (S1, +1; S2, +2; S27, +1) are also noted. Seven participants, including business representatives (SP14; SP17; SP18; SP19) and policymakers (SP6; SP7) and a researcher (SP21), align with this view, stressing the need for a more supportive environment and stronger networks to achieve decarbonization goals.

The second Swedish narrative (SE2) *highlights scepticism regarding technological solutions* for decarbonization. While acknowledging the increasing need for renewable electricity (S41, +5), it points out the lack of clear technological pathways and concerns about overreliance on biomass and immature technologies like hydrogen (S13, 1; S51, +2; S14, +4; S10, +2). Though electrification and carbon capture are seen as promising, large-scale implementation faces infrastructure and component access challenges (S41, +5; S44, +4; S45, +2; S46, +3). The narrative questions the feasibility of achieving zero emissions by 2045 (S21, +2) and downplays the urgency, noting that domestic firms already have a smaller climate footprint than international competitors (S29, −5; S22, +4; S54, 0). Four participants, including representatives from metals, cement, and mining industries (SP9, SP10, SP20) and a bank involved in low-carbon technology financing (SP23), align with this view, citing a lack of ready-to-implement projects and insufficient infrastructure support.

The third Swedish narrative (SE3) emphasizes *the need for more guidance and support from policymakers*. While the narrative acknowledges the challenges related to renewable electricity provision (S36, +5; S44, +3), it views the goal of reaching net zero emissions by 2045 as achievable (S21, −5) and sees this as an opportunity to enhance industrial competitiveness (S23, −5). However, the narrative stresses the issues with political leadership, policy regulation, and public investment. It argues that firms competing in global markets (S7, +2) require more substantial support to successfully decarbonize and suggests that policy should compensate stakeholders negatively impacted by the mission to maintain public support for climate goals (S40, +3). The narrative points to the need for strategic coordination, stronger market incentives, and active public procurement to stimulate demand for low-carbon products (S32, +4). Additionally, it criticizes slow environmental permitting processes that hinder the implementation of new technologies (S36, +5; S37, +3) and calls for increased public funding for research, development, and demonstration activities (S38, +2; S39, +3). Six participants, including researchers in collaborative innovation projects (SP5, SP22), representatives from industrial firms (SP24, SP25), a government agency representative (SP12), and a think-tank member (SP3), support this narrative, which underscores the role of policymakers in guiding and facilitating the decarbonization process.

The fourth Swedish narrative (SE4) *focuses on the potential negative consequences of decarbonization*, particularly its impact on cultural values and local ecosystems. This narrative raises concerns about the trade-offs between climate goals and other environmental objectives, such as biodiversity (S24, +5; S25, +5). It criticizes the current focus on new production technologies and renewable energy, arguing that it neglects the need for circularity and more radical system-level change (S9, +4; S42, +4). The narrative also highlights barriers to sustainability, including consumption culture, anthropocentric values, and growth-oriented economic governance. Despite these concerns, the narrative does not perceive a negative impact on the competitiveness of Swedish industry (S23, −5) but worries about potential land-use conflicts and harm to rural businesses due to increased demand for renewable resources (S41, +4). Three participants, including representatives from an indigenous policy organization (SP2), an environmental NGO (SP13), and a regional government administration (SP16), align with this view, emphasizing the need for a more balanced approach that addresses the broader social and environmental challenges alongside decarbonization efforts.

4.1.2. Similarities and differences

The four Swedish narratives have two common traits. First, they all emphasize the need for large amounts of renewable electricity. Although many decarbonization solutions are reliant on large-scale electrification, this agreement may reflect that participants have been influenced by the public debate. During the period when interviews were conducted, problems in the Swedish electricity system (i.e. power supply, transmission capacity and increasing prices) were a salient topic, both in relation to industrial decarbonization and increasing electricity prices in

Europe. Second, none of the narratives consider decarbonization as a threat to the competitive position of Swedish industry. In fact, two of the narratives (SE1, SE2) go even further by seeing decarbonization as a (business) opportunity. These common traits can be seen as parts of a meta-narrative that most actors adhere to, even though their perspectives differ widely in other dimensions. Indeed, there are relatively few consensus statements (see Table A.5) for the Swedish factors. Instead, the narratives are differentiated by the challenges that are deemed most important. SE1 focuses on challenges related to the characteristics of industries and markets, but also acknowledges weak networks and collaboration, poor availability of knowledge and competence and the need for policy support. In contrast, SE2 emphasizes challenges related to technology, together with the availability of related knowledge and competence. The strongest focus on a specific aspect is offered by SE3 which highlights the lack of policy support. Lastly, SE4 is particularly concerned with trade-offs that result in negative consequences given the current pathway to zero emissions.

4.2. Norway

4.2.1. Challenge narratives

The first Norwegian narrative (NO1) *emphasizes that process industry decarbonisation is hindered by external, structural conditions*. This includes the lack of a global carbon price (S34, +5) unconducive market (S28, +4; S27, +3; S7, +3) and policy conditions (S53, +4; S32, +3), and lacking infrastructure for CCS (S46, +4) and power (S41, +5; S53, +4). Challenges related to market dynamics are furthermore key distinguishing statements for NO1 (S26, S27, S33). Features of the process industry itself, as well as the technological solutions (S10, −4; S11, −5; S12, −4; S14, −5; S17, −3) and novel business models needed to decarbonize, are not perceived to constitute a challenge to reaching climate targets. By contrast, NO1 conveys a view that other (external or innovation system) actors such as in R&D and the innovation support system provide insufficient support. The seven participants that share this view represent various (energy, minerals, metal etc.) business sectors (NP7, NP10, NP12, NP13, NP15), research/academia (NP19) and policy (NP22).

The second narrative (NO2) *stresses that decarbonization must be accelerated*. This is underpinned by the view that change is too slow (S54, +5), mainly due to lack of crucial inputs (notably electricity) and related infrastructure (S41, +4; S44, +3), and insufficiently mature key technologies (S51, +5; 14, +4)). Distinguishing statements that exemplify this view relate for example to exaggerated beliefs in hydrogen as a solution (S14), and that the EPIS are too concerned with efficiency improvements rather than systemic change (S3). While this attention to acceleration makes it somewhat similar to SE2, NO2 also reflects a view that more concrete action is needed (S30, +3), and that we also need to accept that both industry (S40, −5; S23, −4; S22, −4; S1, −3), cultural groups and nature (S24, −5) may be adversely affected by the necessity of addressing climate mitigation. Compared with the other factors, NO2 stands out in terms of emphasizing that EPI decarbonization needs to be accelerated, and that we must accept that the climate transition creates losers—also within the national economy. The five flagged participants for NO2 represent bio-related EPIs (NP4, NP6), policy (NP21), and research (NP1, NP20).

The third narrative (NO3) *represents a global but also a somewhat pessimistic narrative*, signalling a lack of faith in what is achievable. Compared with the other factors, NO3 ranks the statement “Reaching zero emissions until 2045/2050 is not a realistic goal” much higher than in all other factors (S21, +4). The top ranked statements concern the lack of a global carbon price (S34, +5) and geopolitical instability (S55, +5). The pessimistic sentiment also comes to the fore in relation to the prospects of decarbonizing via electrification (S41, +4; S44, +4; S12, +3), as well as in the climate transition being harmful for exports (S23, ranked two orders higher than other factors). Compared with other NO factors, difficulties of assessing consequences of new technologies are also prominent in NO3 (S52, +1), as seen also in SE4. By contrast, the innovation and support system (S49, −5) is not perceived to constitute a barrier to process industry decarbonisation, nor is access to competence (S16, −5). Four participants share this view, representing metal producers and energy infrastructure (NP14, NP17, NP25) and research (NP24).

The fourth narrative (NO4) *is optimistic with regards to technology*, which is a trait it shares with SE3, despite the lack of key inputs to new technologies being a significant distinguishing statement (S45). Key challenges relate to lack of infrastructure development on the input side (S41, +5; S44, +5; S46, +4), as well as insufficient political leadership (S32, +4; S30, +3; S56, +3). Another main concern is that the climate challenge is not seen to be taken sufficiently seriously (S29, +3). In comparison with the other factors, NO4 emphasises challenges related to lack of finance (S1, +2; S2, +1). As in NO1, NO4 has a positive view of the potential of technology and role played by universities and research institutes, but it is less concerned with challenges on the demand side. Conversely, the financial system is considered a more important bottleneck. The four participants associated with NO4 represent different various business sectors (metals, minerals, refineries, finance, energy) (NP2, NP16, NP23), and an environmental NGO (NP3).

4.2.2. Similarities and differences

The four Norwegian narratives have several shared traits, and while there are important differences, there is overall more alignment in challenge perceptions than in Sweden. This interpretation is supported by the relatively high (compared with Sweden) number of consensus statements (see Table A.5 for an overview) across the Norwegian narratives.

All Norwegian narratives emphasize the need for electricity production and distribution. Another common feature is that recent geopolitical affairs have negatively influenced the conditions for a transition. However, most informants (across the narratives) saw this as temporary, and that the transition may well speed up in response. Statements reflecting other challenges that rank high concern the need for accelerating EPI decarbonization, lack of political direction and coherence, and the lack of a global price on carbon emissions. Statements that are ranked low across the factors reflect that lack of collaboration between different actors and internationally is not considered an important challenge.

Although there is thus considerable alignment across the narratives in the Norwegian case with regards to which challenges are perceived most important, there are also some significant differences. NO1 highlights the need for policies to help facilitate and steer decarbonisation and is optimistic with regards to technology. NO2 emphasizes that the (current) technological solutions are immature, and that the climate issue is more important than other (economic, biodiversity etc.) issues. By contrast, NO3 is distinguished by placing higher weight on the trade-offs between climate mitigation and other environmental (and economic) issues. Lastly, NO4 differs from the other narratives especially in emphasizing the need for stronger leadership and pressure in decarbonization.

4.3. Cross-country analysis

As discussed in Section 2.3, Sweden and Norway have many contextual similarities and differences that are likely to influence how EPI decarbonisation challenges are perceived. This was substantiated in the preceding country-level Q analyses, which form the basis for the cross-country analysis presented below.

To begin with, there appears to be somewhat more alignment among the narratives in Norway than in Sweden. Three of the Swedish narratives (SE2, SE3, SE4) are strongly focused on specific and diverging challenge domains (i.e., technology, policy and trade-offs), while the Norwegian narratives come across as slightly more aligned overall as well as with regards to the challenges that are perceived to be most and least important (Table 1). This is further indicated by the explained variance of the four factors (41 % in Sweden vs. 36 % in Norway, see Table A.2/A.3) and the higher number of consensus statements across the narratives in Norway. Interestingly, none of the consensus statements are similar across the countries, except for "*the process industry supplies a global and highly competitive market*" (S07).

In Norway, the lack of directionality and coordination in policy (S32) is a concern that is ranked high or quite high in all factors, while this is slightly less of a concern in Sweden. This is also mirrored in similar rankings of the statement concerning the lack of policies, strategies and visions leading to concrete activities (S30) in Norway. Aspects related to the innovation support system (reflected in statements concerning e.g. involvement of different types of actors in innovation projects (S50), the sharing of knowledge from R&D projects (S19), and establishing partnerships (S47)) does not appear to be a major concern in any of the countries.

In both countries, there are strong concerns related to the need for upscaling renewable electricity production with competitive pricing (S41) across all factors. Grid expansion (S44) is similarly a challenge that is ranked high in most factors across the countries, save for SE4. There is also a general tendency to perceive the pace of the EPI transition as being too slow (S54), yet in NO3 and SE2 this challenge is considered less prominent. Another statement that is ranked high in several factors (NO1, NO2, NO3, SE1, SE2, SE3) concerns the lack of a global price on carbon emissions (S34). However, this challenge appears to be less of concern in Sweden than in Norway, as seen in the ranking of the statement related to the climate transition being harmful for exports (S23). On the one hand, this may be due to the Norwegian participants' strong concern with the lack of necessary political direction and coordination as well as limited materialization of visions and strategies into concrete activities [58]. In Sweden, these challenges are perceived to be less important, which could reflect an increasing general interest in industrial decarbonisation. Especially large industrial projects in Northern Sweden (e.g. battery production, hydrogen-based steel) are considered beneficial for regional economic growth and employment and have received mostly positive media coverage [59,60]. Although there are positive developments also in Norway, we suspect that the very positive discourse in Sweden has influenced a more optimistic attitude.

On the other hand, the more pronounced concern about global competitiveness in Norway may be due to differences in the Norwegian and Swedish EPIs themselves. Sweden's process industry is to considerable extent based on domestic natural resources (iron ore, lime, biomass). It also supplies large domestic manufacturers that also have ambitious emission reduction targets (e.g. Volvo [61], Skanska [62], IKEA [63]) with key inputs, leading to strong potential positive feedback loops across EPIs and other sectors with regards to climate mitigation. Statements related to a shift towards a circular economy (S09, S42) are generally ranked much higher in Sweden than in Norway, which we also consider to be indicative of differences in economic structures and sectoral couplings in the two countries. While sectoral couplings between EPIs and manufacturing are present also in Norway, Norwegian EPIs typically import much more of the raw material and export their products to global markets, whereas availability of cheap and reliable hydropower and process industry know-how has been key to competitiveness. With increasing costs and future uncertainties related to electricity supply, there is an understandable fear that this comparative advantage may be lost [64].

Concerning technological solutions, views differ considerably across factors in both countries. Out of the four technological solutions that were explicitly considered (biomass, CCS/CCU, electrification, hydrogen), there appears to be most agreement across the factors for electrification (S12). CCS/CCU (S11) receives mixed rankings in both countries, but the differences are apparent in that two of the Norwegian factors (NO1/NO4) signal considerable belief in this solution. CCS has also been high on the climate agenda in Norway for many years, and shifted from O&G to the EPIs [65], while the discourse in Sweden has only quite recently begun emphasizing the potential to produce negative emissions through bio-CCS technology and the possible need to use CCS technology to mitigate emissions from cement production [8]. For hydrogen (S14), the picture is very mixed in both countries, but with slightly more alignment around hydrogen as a decarbonisation solution for EPIs in Sweden. This may be due to the potential for hydrogen to reduce emissions in Sweden's large iron and steel sector [6]. Hydrogen (S14) and biomass (S10) are also interesting in that they are ranked high/low or relatively high/low across most factors.

5. Conclusions and policy implications

Decarbonising EPIs is a formidable task confronting industry and policymakers alike. Echoing previous research, our point of departure is that EPI decarbonisation can be achieved with different solutions [e.g. 28], and is confronted with various problems. Actors often fail to fully acknowledge contestation about these problems and solutions, which may challenge or hinder sufficient agreement to enact the necessary changes to reduce emissions [8,15] or result in inefficient policies [14]. This makes it important to gain a more in-depth understanding of how industry actors, policy makers and other stakeholders perceive problems and solutions associated with EPI decarbonisation [66]. On the one hand, this includes whether there are diverging views on particular decarbonisation solutions, or if decarbonising EPIs comes at the expense of other objectives such as preserving nature or maintaining competitiveness. On the other hand, identifying shared views can allow for complexity reduction in priority-setting, more inclusive policymaking, and a clearer grasp of what ought to be done. In a context with considerable contestation, understanding shared views may be valuable for mobilizing actors, networks and interest groups that may otherwise disagree on key issues that need to be solved before major policy and investment decisions can be made.

Our use of Q methodology constitutes one approach to identifying shared and/or contested views on how an overarching societal challenge such as decarbonizing EPIs should or could be addressed. In the subsections that follow, we briefly summarize key findings and discuss implications for policy makers and practitioners as well as limitations and suggestions for future research.

5.1. Key findings

The Q analysis resulted in four distinct narratives in each country, reflecting misalignment in the perception of decarbonisation challenges. Several themes reoccur in both Swedish and Norwegian narratives, including scepticism towards technological solutions (for different reasons) (e.g. SE2, NO2), calls for more active policymaking (e.g. SE3, NO1), and concerns about trade-offs between climate goals and other social and environmental objectives (e.g. SE4, NO3). These themes are sometimes pronounced in similar ways across the identified narratives (e.g., SE2 and NO3), but more often, they are combined and rationalized in different ways. For instance, both NO2 and SE4 highlight trade-offs that accompany EPI decarbonisation, but whereas NO2 argues that this should not prevent continued and strengthened action along the current pathway, SE4 rather calls for alternative trajectories towards completely closed and circular material flows through degrowth and reduced consumption.

The analysis also revealed alignment in how some decarbonisation challenges are perceived. Most notably there is widespread agreement across the two countries that EPI decarbonisation hinges on expanding the supply and distribution of electricity, a challenge that we would expect is present in most other countries globally. Some decarbonisation challenges are, however, perceived differently when comparing at the country level. For example, Norwegian participants are more sceptical towards the possibility of reaching the climate goals. This could be related to the high levels of public protests towards expanding both (renewable) energy production and transmission grids, but also reflect previous experience of insufficient efforts to convert policy visions into implemented policy instruments.

5.2. Policy recommendations

Our findings highlight that the need to develop and expand the necessary infrastructure for EPI decarbonisation (most notably in renewable energy production and distribution) is acknowledged in both Norway and Sweden, but there are also strong concerns that this may have negative implications for example for nature or marginalised groups. Both countries currently have entities set-up to provide recommendations and/or funding for EPI decarbonisation, such as 'Industriklivet' in Sweden and 'Prosess21' in Norway, that typically represent the interests of industry, government and research actors. Moving forward, such entities should consult with broader stakeholder groups, such as environmental NGOs and indigenous communities. Given the complexity of EPI decarbonisation with regards to actual impacts and trade-offs, another recommendation is to provide knowledge and planning support to regional and local authorities that for example approve of large-scale infrastructure development, especially for power production.

Norway and Sweden are in a common electricity market and have collaborated on expanding the deployment of renewables [46]. Further collaboration between the two countries to ensure sufficient electricity generation and distribution capacity as well the development of other infrastructure (e.g. for CCS/CCU) can be an important step moving forward to allow for EPI decarbonisation. In doing so, however, it is paramount that major concerns, for example related to biodiversity, are considered, and that adversely affected groups are compensated.

A specific recommendation for policy makers in Norway, reflecting the perceived lack of directionality and lack of belief in that the extant (vague) target is achievable, is to set a de facto net-zero target, including more sector-specific targets with clear roadmaps for how this can be achieved. Another is to provide sufficient policy support to ensure that more ambitious large-scale pilot and demonstration projects materialize. For Sweden, a specific recommendation is that more attention and policy support is directed towards enabling circular material flows, and to ensure more rapid environmental permitting processes. As mentioned, however, these need to be designed in such a way that they ensure democratic participation.

These general and specific policy recommendations are relevant also to other countries that need to expand low-carbon energy production and distribution, infrastructure for CCU/CCS, and circular material flows, all demanding large investment and considerable innovation. Considering that EPI decarbonisation is closely coupled with the energy system transition [67], countries that have large energy-related emissions arguably face a more daunting challenge than Norway and Sweden. Countries will also differ with regards to conditions, prospects and politically set targets for implementing particular solutions [8], as well as how trade-offs between EPI decarbonisation and other concerns are handled.

5.3. Limitations and future research

While this paper to the best of our knowledge provided a first-of-its kind (comparative) empirical analysis of perceptions of EPI decarbonisation challenges in two countries using Q methodology, a limitation is that both Norway and Sweden are high-income countries with progressive GHG emission reduction goals. Insights from our analysis are nevertheless relevant for climate mitigation also in other countries. Although the EPIs are off track to reduce GHG emissions both globally and in Europe [1,68], the budding decarbonisation of the 'hard-to-abate' sectors marks the beginning of a qualitatively different phase of the energy transition [67]. As this paper has shown, conditions for EPI decarbonisation differ considerably between countries and regions due to factors such as resource availability, the competitiveness of industry, and policy targets and priorities. For example, steelmaking is currently concentrated and expanding in Southeast Asia, the Middle East, and North Africa, where availability of fossil resources has been abundant, and where the polluters-pay principle does not yet apply [69]. Significant policy changes that are underway, such as the introduction of the EU's Carbon Border Adjustment Mechanism and phase out of free allowances within EU-ETS [70], will surely tilt the playing field in steelmaking and other EPIs, and likely provide opportunities for countries with a clean energy mix and availability of cheap electricity to increase their global EPI market share. Such aspects related to positioning in global markets are likely to influence the shaping of EPI decarbonisation narratives and accentuates the relevance of the approach presented in this paper for formulating decarbonisation policies in different countries, and, in turn, for reducing global emissions from EPIs. We thus welcome studies of EPI decarbonisation challenges in other countries using Q methodology.

Methodologically, the empirical scope of the paper covering two countries and what is arguably a highly heterogeneous type of economic activity (i.e. the EPIs) also has limitations. Future research could do more focused Q studies on specific EPI sectors (e.g. metals or petrochemicals) for more detailed understandings of opportunities and challenges for decarbonisation. Such more focused research designs could also provide more in-depth analysis than was possible in this paper by triangulating different data sources. Another limitation, which is shared by most Q studies, is that the composition of the p-sample has a strong influence on the results. Although we did our best to recruit participants with different perspectives, it cannot be ruled out that important viewpoints are not represented and thus not reflected in the identified narratives. This also highlights the need for complementary survey research based on larger samples, especially to strengthen the statistical rigour of the comparative analysis. Finally, we urge other social science researchers to also explore how Q methodology can enrich the methodological toolbox used for studies of energy and sustainability transitions.

CRediT authorship contribution statement

Markus Steen: Writing – original draft, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Johnn Andersson:** Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Hans Hellsmark:** Writing – original draft, Validation, Project administration, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Teis Hansen:** Writing – original draft, Validation, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Jens Hanson:** Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Elizaveta Johansson:** Writing – original draft, Validation, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

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.

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Appendix

Table A.1
Performed Q interviews in Sweden and Norway (i.e., the p-sample).

ID	Perspective	Position	Interviewer	Date
Sweden				
SP1	NGO	Director	EJ	2022-05-23
SP2	Policy, state agency	Project Manager	JA	2022-05-16
SP3	NGO	Policy Analyst	JA	2022-04-01
SP4	Business, metals	VP of Product	EJ	2022-04-08
SP5	Research, applied research institute	Senior Researcher	EJ	2022-03-23
SP6	Policy, state agency	Climate Analyst	JA	2022-04-11
SP7	Policy, funder	Director	HH	2022-05-10
SP8	Research, applied research institute	Researcher	HH	2022-04-12
SP9	Business, metals	Managing Director	JA	2022-05-03
SP10	Business, cement	Director of Development	EJ	2022-04-06
SP11	Business, metals	Product Manager	EJ	2022-04-07
SP12	Policy, state agency	Specialist	EJ	2022-04-26
SP13	NGO	Senior Strategist	EJ	2022-04-05
SP14	Business, carbon management	Director	JA	2022-03-24
SP15	Business, equipment manufacturing	Business Developer	EJ	2022-03-22
SP16	Policy, regional authority	Head of R&D	HH	2022-06-23
SP17	Business, energy	Business Development Director	JA	2022-05-16
SP18	Business, chemicals	VP of Strategy	EJ	2022-04-28
SP19	Business, vehicles	Head of Sustainability	EJ	2022-03-30
SP20	Business, minerals	Project Manager	EJ	2022-05-10
SP21	Research, university	Professor	JA	2022-04-11
SP22	Research, applied research institute	Senior Researcher	HH	2022-05-04
SP23	Business, finance	Sustainability Expert	JA	2022-03-28
SP24	Business, energy	Head of Sustainability	HH	2022-05-05
SP25	Business, refining	Director, Project Finance	HH	2022-04-12
Norway				
ID	Perspective	Position	Interviewer	Date
NP1	Research, university	PhD Fellow	MS	2022-05-06
NP2	Business, cluster organisation	CEO	MS	2022-05-31
NP3	NGO	Senior Advisor	JH	2022-06-09
NP4	Business, bioproducts	Senior Engineer	MS	2022-06-20
NP5	Policy, funding	Special Advisor	JH	2022-06-27
NP6	Business, cluster organisation	CEO	JH	2022-06-30
NP7	Business, energy	Manager	MS	2022-07-28
NP8	Policy, funding	Head of Division	JH	2022-08-03
NP9	Business, industry organisation	Area Manager	MS	2022-08-09
NP10	Business, minerals	CEO	MS	2022-08-10
NP11	NGO	Area Manager	MS	2022-08-10
NP12	Trade union	Director	MS	2022-08-11
NP13	Business, cluster organisation	CEO	MS	2022-08-12
NP14	Business, metals	Climate Director	MS	2022-08-12
NP15	Business, chemicals	VP of Sustainability	JH	2022-08-15
NP16	Business, finance	Head of Section	MS	2022-08-16
NP17	Business, metals	VP of Product	JH	2022-08-29
NP18	Research, university	Professor	MS	2022-09-02
NP19	Research, university	Professor	JH	2022-09-09
NP20	Research, applied research institute	Senior Business Developer	MS	2022-09-12
NP21	Policy, funding	Special Advisor	JH	2022-09-16
NP22	Policy, state agency	Area Manager	MS	2022-09-23
NP23	Business, energy	Director	MS	2022-09-26
NP24	Research, applied research institute	Senior Researcher	JH	2022-09-26
NP25	Business, energy infrastructure operator	VP of Operations	MS	2022-09-28

Table A.2
Summary of factors from the Swedish analysis.

	SE1	SE2	SE3	SE4
Eigenvalue	5.92	1.63	1.20	1.13
Defining Q sorts	7	4	7	3
Explained study variance	24 %	7 %	5 %	5 %
Standard error of factor z-scores	0.19	0.24	0.19	0.28
Factor correlations (F1/F2/F3/F4)	1/0.09/0.60/0.33	0.09/1/0.12/0.01	0.60/0.12/1/0.40	0.33/0.01/0.40/1

Table A.3
Summary of factors from the Norwegian analysis.

	NO1	NO2	NO3	NO4
Eigenvalue	4.84992	1.74124	1.37404	1.14554
Defining Q sorts	7	5	4	4
Explained study variance	19 %	7 %	5 %	5 %
Standard error of factor z-scores	0.19	0.22	0.24	0.24
Factor correlations (F1/F2/F3/F4)	1/0.28/0.30/0.48	0.28/1/0.21/0.27	0.30/0.21/1/0.18	0.48/0.27/0.18/1

Table A.4
Factor loadings of participants' Q sorts. Bold indicates significant loading on the factor ($p < 0.05$).

Sweden					*Norway*				
ID	SE1	SE2	SE3	SE4	ID	NO1	NO2	NO3	NO4
SP1	0.33394	−0.39375	0.01728	0.50846	NP1	0.02914	**0.50936**	0.24622	0.12911
SP2	−0.15191	0.02579	0.0569	**0.51261**	NP2	0.1455	0.25352	−0.06111	**0.50168**
SP3	0.2445	0.13204	**0.68668**	0.14661	NP3	0.09329	0.25446	0.11365	**0.52418**
SP4	0.05886	0.39212	0.3027	0.4615	NP4	−0.25748	**0.42472**	0.24629	0.05564
SP5	0.25021	0.27924	**0.64061**	0.28884	NP5	0.11564	0.03901	0.40428	0.39569
SP6	**0.45773**	0.09822	0.13919	0.38872	NP6	0.25978	**0.57467**	−0.02914	0.29433
SP7	**0.60626**	0.15772	0.12373	0.19444	NP7	**0.35781**	0.04706	−0.07334	0.1195
SP8	−0.03242	0.16959	**−0.38154**	0.05802	NP8	0.18579	−0.01643	0.41385	0.39722
SP9	−0.11576	**0.42231**	−0.23352	−0.12445	NP9	0.31762	0.46809	0.07399	0.38621
SP10	0.03709	**0.45565**	0.0303	−0.04331	NP10	**0.48213**	0.01777	0.20711	−0.01984
SP11	0.21427	0.41114	−0.00751	0.41143	NP11	−0.28472	0.26039	0.12336	0.35655
SP12	0.30169	0.10703	**0.42193**	0.15607	NP12	**0.59235**	0.21785	0.17419	0.21127
SP13	0.27447	−0.21907	0.27595	**0.56698**	NP13	**0.43225**	0.22563	0.20191	−0.02233
SP14	**0.42765**	−0.04089	0.10289	0.04237	NP14	0.09434	−0.03647	**0.50427**	−0.03185
SP15	0.34495	0.04601	0.29761	0.33835	NP15	**0.60193**	−0.1169	0.03857	0.15742
SP16	0.27432	0.23098	0.11005	**0.44865**	NP16	0.17215	0.10139	0.01689	**0.38853**
SP17	**0.7305**	−0.09522	0.24966	0.11599	NP17	0.03939	0.11697	**0.3858**	0.03301
SP18	**0.63759**	0.09735	0.16567	−0.03272	NP18	−0.34288	0.24979	0.37264	0.50504
SP19	**0.5209**	0.1176	0.17132	0.19859	NP19	**0.50728**	0.08619	0.38157	0.31667
SP20	−0.00204	**0.38389**	0.12559	0.04285	NP20	0.08149	**0.61373**	−0.10331	0.1978
SP21	**0.57231**	−0.09559	0.38833	−0.151	NP21	0.04917	**0.68438**	0.1556	0.01007
SP22	0.2741	−0.20582	**0.63529**	0.21193	NP22	**0.50827**	0.07083	0.11107	0.35112
SP23	0.18603	**0.49174**	−0.01269	0.25408	NP23	0.28181	−0.00484	0.11913	**0.81609**
SP24	0.12688	0.30206	**0.41416**	0.12525	NP24	0.06284	0.13068	**0.50631**	0.00848
SP25	0.40236	0.15499	**0.58806**	0.09247	NP25	0.0441	0.04317	**0.37129**	0.13438

Table A.5
Consensus statements.

Statements	S.ID	NO1	NO2	NO3	NO4	SE1	SE2	SE3	SE4
Climate demands on the capital market are too low	S01			■					
The process industry supplies a global and highly competitive market	S07				■		■		■
The climate transition is oriented towards too few technological alternatives	S13				■				
Knowledge about new business models is lacking	S18							■	■
Knowledge from research and development projects is not diffused among actors in the climate transitions	S19		■						
The climate transition will harm SE/NO exports	S23							■	
Visions, strategies and plans within the climate transition do not lead to concrete activity	S30	■	■	■	■	-			
There is a lack of political direction, overview and coordination	S32	■		■					
There is a lack of long-term policy instruments at the EU level (i.e. emissions allowances, carbon tolls, investment programs)	S35		■						
Public support to research and development of new technology is insufficient	S39		■						
The climate transition requires large amounts of electricity with competitive pricing	S41		■		■				
There is a lack of circular flows that give the process industry access to recycled raw material	S42	■	■		■				
The possibility of increasing the production of biomass from Swedish/Norwegian forests is contested	S43					■	■	■	■
The expansion of the electricity grid is too slow	S44			■					
It is difficult to establish partnerships among industrial companies, suppliers and customers	S47		■	■					
There is a lack of collaboration among Swedish/Norwegian and international actors	S48		■						
Important actors, such as customers, suppliers and specialists are missing in innovation projects	S50					■			
It is difficult to understand the consequences of new technologies	S52	■	■						

Table A.6
Main decarbonisation options for the process industry [3,4,8].

Solution	*Type*	*Applicability (main sectors)*	Comment
Electrification	Energy input	All industrial sectors	Becomes a direct or indirect solution by the means of substituting thermochemical processes but also part of other solutions such as CCS and hydrogen.
Hydrogen (green/ blue)	Energy and/or resource input	Refineries, chemicals, fertilizer, iron and steel	Hydrogen requires significant increases in renewable electricity production (green), or reformation of natural gas (with CCS), but also associated infrastructure for transport and storage.
Carbon capture (utilisation) and/or storage (CCS/CCU/ CCUS)	End-of-pipe solution if combined with storage, but can also generate new resources if combined with hydrogen (e-fuels)	All industrial sectors. CCS is especially relevant in cement industry that have few other options and CCU in petrochemical industry	Capture potential depends on flue gas composition. If used on biogenic flue gases it can enable negative emissions. Associated compression and storage require significant increase in electricity production, grid capacity, transport and storage solutions
Biomass and other alternative feedstocks	Energy and/or resource input	All industrial sectors	Scalability and resource availability is a limiting factor in the case of biomass but can be significant when combined with other solutions. A largely untapped potential for developing alternative binders in cement industry.
Re-use and recycling	Increased utilization of waste heat, reused materials and recycled feed stock.	All industries	Iron and steel already implement a high degree of recycling, but there is a significant and untapped potential in plastic recycling and
Energy and material efficiency	Energy input (reduced)	All industrial sectors	Important, but insufficient for net-zero emission as standalone solution

Data availability

Data will be made available on request.

References

[1] IEA, Industry. https://www.iea.org/energysystem/industry, 2023 (accessed 21 November 2023).
[2] J. Rockström, O. Gaffney, J. Rogelj, M. Meinshausen, N. Nakicenovic, H. J. Schellnhuber, A roadmap for rapid decarbonization, Science 355 (2017) 1269–1271, https://doi.org/10.1126/science.aah3443.
[3] I.A. Bashmakov, L.J. Nilsson, A. Acquaye, C. Bataille, J.M. Cullen, S. de la Rue du Can, M. Fischedick, Y. Geng, K. Tanaka, Industry, in IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel On Climate Change, P.R. Shukla, et al, Cambridge University Press, Cambridge, UK and New York, NY, USA. https://doi.org/10.1017/9781009157926.013.
[4] L.J. Nilsson, F. Bauer, M. Åhman, F.N.G. Andersson, C. Bataille, S. de la Rue du Can, K. Ericsson, T. Hansen, B. Johansson, S. Lechtenböhmer, M. van Sluisveld, V. Vogl, An industrial policy framework for transforming energy and emissions intensive industries towards zero emissions, Climate Policy 21 (2021) 1053–1065, https://doi.org/10.1080/14693062.2021.1957665.
[5] B.K. Sovacool, M.D. Bazilian, J. Kim, S. Griffiths, Six bold steps towards net-zero industry, Energy Res. Soc. Science. 99 (2023) 103067, https://doi.org/10.1016/j.erss.2023.103067.
[6] E. Karakaya, C. Nuur, L. Assbring, Potential transitions in the iron and steel industry in Sweden: towards a hydrogen-based future? J. Clean. Prod. 195 (2018) 651–663, https://doi.org/10.1016/j.jclepro.2018.05.142.
[7] J.H. Wesseling, S. Lechtenböhmer, M. Åhman, L.J. Nilsson, E. Worrell, L. Coenen, The transition of energy intensive processing industries towards deep decarbonization: characteristics and implications for future research, Ren. Sust. En. Rev. 79 (2017) 1303–1313, https://doi.org/10.1016/j.rser.2017.05.156.
[8] T. Hansen, J. Andersson, J. Finstad, J. Hanson, H. Hellsmark, T. Mäkitie, A. Nordholm, M. Steen, How aligned are industry strategy and government policy for the decarbonization of energy-intensive process industries? Clim. Pol. 24 (2024) 1149–1162, https://doi.org/10.1080/14693062.2024.2363490.
[9] F. Bauer, T. Hansen, L.J. Nilsson, Assessing the feasibility of archetypal transition pathways towards carbon neutrality – A comparative analysis of European industries, Resour., Conserv. Recycl. 177 (2022) 106015, https://doi.org/10.1016/j.resconrec.2021.106015.
[10] M.A.E. van Sluisveld, H.S. de Boer, V. Daioglou, A.F. Hof, D.P. van Vuuren, A race to zero - Assessing the position of heavy industry in a global net-zero CO2 emissions context. Energy, Climate Change 2 (2021) 100051, https://doi.org/10.1016/j.egycc.2021.100051.
[11] C. Bataille, L.J. Nilsson, F. Jotzo, Industry in a net-zero emissions world: new mitigation pathways, new supply chains, modelling needs and policy implications. Energy, Climate Change 2 (2021) 100059, https://doi.org/10.1016/j.egycc.2021.100059.
[12] A. Nurdiawati, F. Urban, Towards deep decarbonisation of energy-intensive industries: a review of current status, technologies and policies, Energies 14 (2021) 2408, https://doi.org/10.3390/en14092408.
[13] S. Griffiths, B.K. Sovacool, D.D. Furszyfer Del Rio, A.M. Foley, M.D. Bazilian, J. Kim, J.M. Uratani, Decarbonizing the cement and concrete industry: a systematic review of socio-technical systems, technological innovations, and policy options, Renew. Sust. Energy Rev. 180 (2023) 113291, https://doi.org/10.1016/j.rser.2023.113291.
[14] M.J. Janssen, J. Wesseling, J. Torrens, K.M. Weber, C. Penna, L. Klerkx, Missions as boundary objects for transformative change: understanding coordination across policy, research, and stakeholder communities, Science. Publ. Pol. 50 (2023) 398–415, https://doi.org/10.1093/scipol/scac080.
[15] I. Wanzenböck, J. Wesseling, K. Frenken, M.P. Hekkert, K.M. Weber, *A framework for mission-oriented innovation policy: alternative pathways through the problem–solution space*, Science. Publ. Pol. 47 (2020) 474–489, https://doi.org/10.1093/scipol/scaa027.
[16] P. Stenner, S. Watts, Doing Q Methodological Research: Theory, Method & Interpretation, Sage, London, 2012. http://digital.casalini.it/9781446258743.
[17] Naturvårdsverket, Sveriges utsläpp av växthusgaser. https://www.naturvardsverket.se/data-och-statistik/klimat/sveriges-utslapp-och-upptag-av-vaxthusgaser 2023 (accessed 20 December 2023).
[18] Miljøstatus, Klimagassutslipp fra industri. https://miljostatus.miljodirektoratet.no/tema/klima/norske-utslipp-av-klimagasser/klimagassutslipp-fra-industri/, 2024 (accessed 5 August 2024).
[19] Swedish Government, Klimatlag. https://www.riksdagen.se/sv/dokument-och-lagar/dokument/svensk-forfattningssamling/klimatlag-2017720_sfs-2017-720/, 2017 (accessed 20 December 2023).
[20] Ministry of Climate and Environment, Meld. St. 12 (2020-2021) Klimaplan for 2021-2030. https://www.regjeringen.no/contentassets/a78ecf5ad2344fa5ae4a394412ef8975/nn-no/pdfs/stm202020210013000dddpdfs.pdf, 2021 (accessed 18 December 2023).
[21] W. Stephenson, The Study of behavior: Q-technique and Its Methodology, The University of Chicago Press, Chicago, 1953.
[22] IEA, Net Zero by 2050 Scenario. https://www.iea.org/data-and-statistics/data-product/net-zero-by-2050-scenario#data-sets, 2021 (accessed 18 December 2023).
[23] IEA, The Future of Petrochemicals. https://iea.blob.core.windows.net/assets/bee4ef3a-8876-4566-98cf-7a130c013805/The_Future_of_Petrochemicals.pdf, 2018 (accessed 18 December 2023).
[24] IEA, Technology Roadmap: low-Carbon Transition in the Cement Industry. https://iea.blob.core.windows.net/assets/cbaa3da1-fd61-4c2a-8719-31538f59b54f/TechnologyRoadmapLowCarbonTransitionintheCementIndustry.pdf, 2018 (accessed 20 December 2023).
[25] IEA, Transforming Industry through CCUS. https://www.iea.org/reports/transforming-industry-through-ccus, 2019 (accessed 20 December 2023).
[26] Naturvårdsverket, Industri, utsläpp av växthusgaser. https://www.naturvardsverket.se/data-och-statistik/klimat/vaxthusgaser-utslapp-fran-industrin/, 2023 (accessed 20 December 2023).
[27] SSB, 08940: klimagasser, etter utslippskilde, energiprodukt og komponent, GWP-verder etter Kyotoprotokollen (AR4) (avslutta serie) 1990 - 2022, Statistikkbanken (2023). https://www.ssb.no/statbank/table/08940/ (accessed 14 December 2023).
[28] C. Bataille, M. Åhman, K. Neuhoff, L.J. Nilsson, M. Fischedick, S. Lechtenböhmer, B. Solano-Rodriquez, A. Denis-Ryan, S. Stiebert, H. Waisman, O. Sartor, S. Rahbar, A review of technology and policy deep decarbonization pathway options for making energy-intensive industry production consistent with the Paris Agreement,

J. Clean. Prod. 187 (2018) 960–973, https://doi.org/10.1016/j.jclepro.2018.03.107.
[29] SEA, Energiläget i siffror 2023. https://www.energimyndigheten.se/nyhetsarkiv/2023/energilaget-i-siffror-2023/, 2023 (accessed 20 December 2023).
[30] Material Economics, Klimatagenda för Sverige, 2021. https://materialeconomics.com/publications/publication/klimatagenda-for-sverige (accessed 14 December 2023).
[31] Swedish Environmental Protection Agency, El Och fjärrvärme, Utsläpp Av Växthusgaser, 2024. https://www.naturvardsverket.se/data-och-statistik/klimat/vaxthusgaser-utslapp-fran-el-och-fjarrvarme/ (accessed 28 October 2024).
[32] Swedish Environmental Protection Agency, Biogena Koldioxidutsläpp Och Klimatpåverkan, 2023. https://www.naturvardsverket.se/amnesomraden/klimatomstallningen/omraden/klimatet-och-skogen/biogena-koldioxidutslapp-och-klimatpaverkan/ (accessed 10 January 2024).
[33] Swedish Environment Agency, Första, andra, tredje… Förslag på utformning av ett stödsystem för bio-CCS. https://www.regeringen.se/contentassets/d232104ea40d4234a5ffde3fe7d48b37/forsta-andra-tredje-forslag-pa-utformning-av-ett-stodsystem-for-bio-ccs.pdf, 2021 (accessed 14 December 2023).
[34] Swedish Government, Fem nordeuropeiska länder ingår bilaterala överenskommelser om export av koldioxid för permanent lagring. https://www.regeringen.se/pressmeddelanden/2024/04/fem-nordeuropeiska-lander-ingar-bilaterala-overenskommelser-om-export-av-koldioxid-for-permanent-lagring/, 2024 (accessed 20 August 2024).
[35] Klimat- och näringslivsdepartementet, Ett Klimatpolitiskt Ramverk För Sverige, 2017. https://www.regeringen.se/contentassets/033bd3e0a16a4d088e20c6e6b5d6b3d3/ett-klimatpolitiskt-ramverk-for-sverige.pdf (accessed 10 January 2024).
[36] Swedish Climate Policy Council, Report of the Swedish Climate Policy Council 2020, 2020. https://www.klimatpolitiskaradet.se/wp-content/uploads/2020/05/2020reportoftheswedishclimatepolicycouncil.pdf (accessed 12 January 2024).
[37] Swedish Government, Tilläggsdirektiv (M2020:50) till initiativet Fossilfritt Sverige (M 2016:05). https://www.regeringen.se/rattsliga-dokument/kommittedirektiv/2020/05/dir.-202050, 2020 (accessed 12 January 2024).
[38] H. Hellsmark, J. Andersson, B. Hedeler. Leaders and laggards: the role of incumbents in transformative policy missions. Under Review in a Journal/Forthcoming.
[39] J. Andersson, H. Hellsmark, Directionality in transformative policy missions: the case of reaching net zero emissions in the Swedish process industry, J. Clean. Prod. 437 (2024) 140664, https://doi.org/10.1016/j.jclepro.2024.140664.
[40] Prosess21, Hovedrapport. https://www.prosess21.no/contentassets/d4c74305ab764cf2b24f3f61f0514f5d/prosess21_rapport_hovedrapport_web-1.pdf, 2021 (accessed 9 January 2024).
[41] Miljødirektoratet, Grønn omstilling: klimatiltaksanalyse for petroleum, industri og energiforsyning. https://www.miljodirektoratet.no/publikasjoner/2022/september/gronn-omstilling-klimatiltaksanalyse/, 2022 (accessed 10 January 2024).
[42] NOU, Mer av alt - raskere. Energikommisjonens Rapport, 2023. https://www.regjeringen.no/contentassets/5f15fcecae3143d1bf9cade7da6afe6e/no/pdfs/nou202320230003000dddpdfs.pdf (accessed 9 January 2024).
[43] IEA, Norway 2022. Executive Summary, 2022. https://www.iea.org/reports/norway-2022/executive-summary (accessed 3 January 2023).
[44] Ministry of Oil and Energy, Meld.St.33 (2019-2020) Langskip - fangst og lagring av CO2, https://www.regjeringen.no/contentassets/943cb244091d4b2fb3782f395d69b05b/nn-no/pdfs/stm201920200033000dddpdfs.pdf, 2020 (accessed 9 January 2024).
[45] M. Steen, A.D. Andersen, J. Finstad, T. Hansen, J. Hanson, K. Jordal, T. Mäkitie, A. Nordholm, M. Ryghaug, A. Santoalha, CCS technological innovation system dynamics in Norway, Int. J. Greenhouse Gas Contr. 136 (2024) 104171, https://doi.org/10.1016/j.ijggc.2024.104171.
[46] J.B. Skjærseth, T. Hansen, J. Donner-Amnell, J. Hanson, T.H.J. Inderberg, H. Ø. Nielsen, B. Nygaard, M. Steen, Wind Power Policies and Diffusion in the Nordic Countries. Comparative Patterns, Palgrave Macmillan, Cham, 2023.
[47] Swedish Energy Agency, Nationell strategi för en hållbar vindkraftsutbyggnad. https://www.energimyndigheten.se/energisystem-och-analys/elproduktion/vindkraft/gemensamt-initiativ-for-en-hallbar-vindkraftsutbyggnad/, 2021 (accessed 10 January 2024).
[48] J.B. Skjærseth, K. Rosendal, Implementing the EU renewable energy directive in Norway: from Tailwind to Headwind, Environ. Pol. 32 (2023) 316–337, https://doi.org/10.1080/09644016.2022.2075153.
[49] D. Lindvall, Why municipalities reject wind power: a study on municipal acceptance and rejection of wind power instalments in Sweden, Energy Pol 180 (2023) 113664, https://doi.org/10.1016/j.enpol.2023.113664.
[50] SSB, Klimagassutslippene gikk ned i 2022. https://www.ssb.no/natur-og-miljo/forurensning-og-klima/statistikk/utslipp-til-luft/artikler/klimagassutslippene-gikk-ned-i-2022, 2023 (accessed 4 September 2024).
[51] Miljøstatus, Klimagassutslipp fra olje- og gassutvinning i Norge. https://miljostatus.miljodirektoratet.no/tema/klima/norske-utslipp-av-klimagasser/klimagassutslipp-fra-olje–og-gassutvinning/, 2023 (accessed 6 November 2023).
[52] S.R. Brown, Political subjectivity: Applications of Q methodology in Political Science, Yale University Press, London, 1980.
[53] R. Carmenta, A. Zabala, W. Daeli, J. Phelps, Perceptions across scales of governance and the Indonesian peatland fires, Glob. Environ. Change. 46 (2017) 50–59, https://doi.org/10.1016/j.gloenvcha.2017.08.001.
[54] K. Hobson, S. Niemeyer, Public responses to climate change: the role of deliberation in building capacity for adaptive action, Glob. Environ. Change. 21 (2011) 957–971, https://doi.org/10.1016/j.gloenvcha.2011.05.001.
[55] J. Andersson, H. Hellsmark, E. Johansson, *The Nature of Contestation in Transformative Policy Missions: a Q Study on the Decarbonization of Swedish Industry*. Under review. Pre-print available at: https://doi.org/10.2139/ssrn.4936945.
[56] L. Guttman, Some necessary conditions for common-factor analysis, Psychometrika 19 (1954) 149–161. https://link.springer.com/article/10.1007/BF02289162.
[57] H.F. Kaiser, The application of electronic computers to factor analysis, Educ. Psychol. Measur. 20 (1960) 141–151, https://doi.org/10.1177/001316446002000116.
[58] L. Scordato, M.M. Bugge, T. Hansen, A. Tanner, O. Wicken, Walking the talk? Innovation policy approaches to unleash the transformative potentials of the Nordic bioeconomy, Science Publ. Pol. 49 (2022) 324–346, https://doi.org/10.1093/scipol/scab083.
[59] Dagens Nyheter, "Norra Sverige världsledande i klimatomställningen". https://www.dn.se/debatt/norra-sverige-varldsledande-i-klimatomstallningen/, 2022 (accessed 13 November 2023).
[60] S.V.D. Näringsliv, Satsningar i norr beräknas ge 50 000 nya jobb. https://www.svd.se/a/onQ4X0/satsningar-i-norr-beraknas-ge-50000-nya-jobb, 2023 (accessed 29 August 2023).
[61] Volvo, Hållbarhet. https://www.volvocars.com/se/v/sustainability/climate-action, 2023 (accessed 17 January 2024).
[62] Skanska. Våra klimatmål. https://www.skanska.se/om-skanska/hallbarhet/klimatneutralitet/, 2023 (accessed 17 January 2024).
[63] IKEA, Klimatåtgärder. https://www.ikea.com/se/sv/this-is-ikea/climate-environment/klimatatgaerder-pub85dbcef0, 2023 (accessed 17 January 2024).
[64] L. Eie, I.M. Sigurdsen, Smelteverk i Norge: – Vanskelig å være konkurransedyktig. https://www.nrk.no/sorlandet/smelteverk-i-norge_-_-vanskelig-a-vaere-konkurransedyktig-1.16649491, 2023 (accessed 15 January 2024).
[65] J. Finstad, A.D. Andersen, Multi-sector technology diffusion in urgent net-zero transitions: niche splintering in carbon capture technology, Tech. Forec. Soc. Change 194 (2023) 122696, https://doi.org/10.1016/j.techfore.2023.122696.
[66] A. Stirling, Keep it complex, Nature 468 (2010) 1029–1031, https://doi.org/10.1038/4681029a.
[67] J. Markard, D. Rosenbloom, Phases of the net-zero energy transition and strategies to achieve it, in: K. Araujo (Ed.), Routledge Handbook of Energy Transitions, Routledge, London, 2022, pp. 102–123.
[68] L.C. Vieira, M. Longo, M. Mura, Are the European manufacturing and energy sectors on track for achieving net-zero emissions in 2050? An empirical analysis, Energy Pol 156 (2021) 112464, https://doi.org/10.1016/j.enpol.2021.112464.
[69] OECD, Latest Developments in Steelmaking Capacity 2023, 2023, https://doi.org/10.1787/c66e1cf9-en (accessed 10 January 2024).
[70] European Commission, Our Ambition For 2023, 2023. https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/our-ambition-2030_en (accessed 9 January 2024).