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How aligned are industry strategy and government policy for the decarbonization of energy-intensive process industries?

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ABSTRACT

Decarbonization of energy-intensive process industries (EPIs) is a central unresolved challenge for limiting global warming to 1.5°C or well-below 2°C. In this article, we investigate the alignment between government policy and applicable industry strategy in decarbonization efforts across six European countries – Denmark, Germany, Netherlands, Norway, Sweden and the United Kingdom. We distinguish between 'target alignment' (How comparable are the size of the emission reduction commitments?), 'temporal alignment' (How closely do the timelines match?) and 'solution alignment' (Are the same types of solutions prioritized?). Based on an analysis of national policy documents, company strategies of the 10 largest emitting EPI plants in each country, as well as secondary sources, we find high target alignment. However, we find substantially lower temporal alignment as emitters are reluctant to commit to intermediate targets that match the decarbonization timelines laid out in national government policy. Solution alignment is intermediate across all six countries as emitters generally pursue the decarbonization options prioritized in policy, but with most emitters remaining at the level of ambitions or plans and few examples of commercial investments so far.

Key policy insights

- Public policies across the analysed countries mainly prioritize CCUS, hydrogen and electrification as decarbonization solutions.
- Large emitters formulate ambitions or plans for the prioritized decarbonization options, but actual investment commitment remains limited.
- Governments should continuously survey alignment of their policy targets and prioritized decarbonization options with industry targets and activities.
- In particular, intermediate targets set by the largest emitters do not match those of national governments.
- Additional support and incentives to make industry act sufficient fast are required.

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1. Introduction

This paper analyses the (mis-)alignment between decarbonization government policy and energy-intensive processing industry (EPI) strategies across six Northern European countries. EPIs supplying iron, steel and other metals, cement, fertilizers, chemicals, refined petroleum products, pulp and paper, and processed food are often characterized as hard-to-abate, implying that reductions of greenhouse gas (GHG) emissions are particularly difficult to achieve. EPIs have significant capital requirements, lengthy investment cycles, relatively slow learning rates and few standardization opportunities due to high complexity and customized production facilities (Bergek et al., 2023). Furthermore, some EPIs, such as cement production, still produce significant amounts of carbon emissions even if produced with 100% renewable energy. Finally, cost-based global competition has negligible potential to instigate EPI decarbonization as there is relatively little pressure from end-consumers (Bergek et al., 2023; Malhotra & Schmidt, 2020).

Despite these significant challenges, technology options for decarbonizing EPIs are available or currently under demonstration. Core options include carbon capture, utilization and storage (CCUS), replacing fossil fuels and raw materials with renewable electricity, hydrogen or biomass, circular material flows, as well as energy efficiency and end-use optimization (Bataille et al., 2018; Bauer et al., 2022). While feasibility of different options varies depending inter alia on industry characteristics, decarbonization of EPIs is no longer a 'mission impossible'.

Furthermore, the Paris Agreement target of limiting global warming to 1.5°C or well-below 2°C stipulates that decarbonization must happen in all industries, including EPIs (Bataille et al., 2021). Consequently, while policies to reduce EPI GHG emissions previously focused on energy efficiency and marginal reductions (Åhman et al., 2017), possibilities for full decarbonization currently receive increasing attention. This includes integrating EPIs into policy schemes in which they were previously exempted. For example, the European Union 'Fit for 55' package suggests removing free allocation of emission allowances in the EU emissions trading system (EU ETS). This indicates an emerging shift in governance towards pursuing a sustainability transition within these industries through a dual aim of developing low-carbon and net-zero strategies and phasing out old polluting practices (Kivimaa & Kern, 2016).

In this context, a core element of EPI decarbonization policy is arguably to set a clear direction for how the industry should develop in the future (Nilsson et al., 2021).[1] However, this is not limited to top-down decision-making from government, but requires joint understanding of decarbonization priorities across government and industry. This is instrumental for accelerating decarbonization towards 2050 net zero goals, especially when accounting for the aforementioned long investment cycles and high capital investments of EPIs.

Consequently, in this paper, we focus on assessing the degree of this joint understanding across government and industry, which we conceptualize as the degree of alignment. Thus, the core research question of the paper is provided in the title: *how aligned are industry strategy and government policy for the decarbonization of EPIs?*

To answer this question, we decompose alignment into different dimensions, drawing on insights from work on policy mixes in transitions (e.g. Bach & Hansen, 2023; Kivimaa & Kern, 2016; Rogge & Reichardt, 2016). A core tenet in policy mix work is that it requires attention to both targets and instruments to understand the influence of policies on transition processes. We mirror this by conceptualizing alignment as dependent on the relationship between the foci of government (on policy targets and policy instruments), and that of EPIs (on firm targets and decarbonization activities). Specifically, we add a conceptual contribution to the existing literature by distinguishing three types of alignment:

First, *target alignment* specifies the extent to which industry actors have set emission reduction targets that are equal to or beyond targets set in government policy. Second, *temporal alignment* reflects whether the target dates for emission reductions proposed by industry actors are in line with or faster than the timeline of the decarbonization policy of the government. Third, *solution alignment* considers whether the

[1]In literatures on innovation studies, this is conceptualised as the 'directionality' challenge, i.e. 'the necessity not just to generate innovations as effectively and efficiently as possible, but also to contribute to a particular direction of transformative change' (Weber & Rohracher, 2012, p. 1042). In other words, innovations are not desirable in and of themselves, and policy should actively steer the direction of innovation towards addressing specific societal challenges (Grillitsch et al., 2021).

decarbonization options (if any) prioritized by governments are also prioritized decarbonization options of industry actors.

We follow Bataille et al. (2016) who suggest that policy implementation at the national level is central to understanding feasibility of different decarbonization options, given substantial variation in industrial, economic and political conditions. Consequently, without disregarding the importance of EU policy for decarbonization efforts (see also discussion), we analyse six Northern European countries – Denmark, Germany, Netherlands, Norway, Sweden and the United Kingdom (UK) – focusing on alignment between national government policy and industry strategy. In the following section, we outline our methodological approach.

The remainder of the paper is organized as follows. The following section presents the methodology, while section 3 characterizes EPIs. Section 4 presents the analysis of the alignment of industry strategy and government policy in the six countries. The final two sections of the paper discuss the results and provide the main conclusions and policy recommendations.

2. Methodology

All six countries share similarities in socio-economic development and are considered relatively ambitious in terms of decarbonization efforts. While there is no widespread agreement on how to assess this (Tørstad et al., 2020), all countries rank high in the Climate Change Performance Index, with Denmark being the highest ranked country and UK the lowest (20th) among the countries analysed here (Burck et al., 2023).[2] We base our analysis on a desktop study of two main sources of documents: first; national policy documents describing decarbonization targets as well as policy instruments of relevance for EPIs and, second, company strategies and documents by the owners of the 10 largest emitting EPI plants in each of the countries, as well as press releases and other secondary sources. The analysis was carried out in early 2023, and the degree of alignment refers to this point in time, with most relevant documents published in the years 2020–2022.

National policy documents were identified through keyword searches (e.g. 'industry' and 'decarbonization') on the websites of relevant national authorities. We also searched for relevant reports and strategies written by other organizations, such as the OECD, NGOs, consultancies, as well as from national public-private partnership arenas. The number of reviewed documents varied with 10 documents for the Norwegian case as the lowest number. Relevant company-level documents were identified on the webpages of the firms, primarily in the form of annual reports, corporate social responsibility reports and press releases.

The assessment of target and temporal alignment is carried out through a comparison of the size and timeline of the envisioned emission reductions by the national governments and the 10 largest EPI emitting plants in the respective countries. *Target alignment* considers whether industry actors are setting ambition levels that are at least equal to those proposed in government policy. Early work by Sullivan (2010, p. 47) on the relationship between climate policies and the responses by the largest European companies found 'a major disconnect between the messages being sent by public policy makers and the actions being taken by companies'. Due to the cumulative character of GHG emissions in the atmosphere, *temporal alignment* might be at least as important as target alignment for climate change mitigation, and multiple studies contend that most companies lack sufficient commitments to reduce emissions (Accenture, 2022; Vieira et al., 2021). While it is beyond the scope of this paper to assess whether industry emitters are on track in terms of emission reduction performance, we consider it important to understand better the temporal (mis)alignment between industry and policy.

In analysing emitters' decarbonization targets, we focus on plant-specific information, rather than company-wide efforts, with the qualification that company-wide targets for full decarbonization were considered to pertain also to the plants in focus (contrary to company-wide goals of partial decarbonization that do not necessitate equal reductions at all facilities). Emitters' reduction targets are compared with governments' reduction targets for EPIs in countries where these are available (e.g. Germany) and otherwise economy-wide reduction targets (e.g. Norway). Our focus is on scope 1 and 2 emissions, while scope 3 emissions (for which data is less readily available) are not considered in the analysis. *Target alignment* is 'high' if emitters have committed to similar reduction levels as in national policy (net-zero in most countries), and 'low' if

[2]Note the three top spots were left vacant to indicate that no country is sufficiently ambitious in their implementation of climate policies.

such commitments are absent. *Temporal alignment* is 'high' if the timeline of reductions is in line with both mid- and long-term national targets, 'intermediate' if it is in line with either mid- or long-term national targets, and 'low' if it is not in line with any of them.[3]

The assessment of *solution alignment* is carried out by comparing prioritized decarbonization options by national governments against those of the 10 largest emitting plants in the respective countries. In assessing governments' prioritized decarbonization options, we focus on which strategies and technology-specific policy instruments are implemented (including the size of funds reserved for specific technologies). We also focus on requirements and implementation choices related to technology-generic policy instruments that indirectly (dis)favour specific technologies. As evident from the analysis, there are considerable differences between the countries in terms of how directly they prioritize technologies: technology priorities are clearly stated in some countries, while they result from interpretations of spendings and policy requirements in other countries. On the company side, preferences in terms of decarbonization options are again assessed for the emitting plants in focus. To assess the maturity of decarbonization action, we introduce a distinction between stated ambitions (e.g. an option is described by the firm as being relevant to the plant), formalized plans (e.g. testing of an option in pilot facilities at the plant), investment decisions (final investment decision is made in an option at commercial scale), and commercialized (an option is implemented at commercial scale). This distinction is relevant as previous research suggests considerable inconsistency across EPIs with regards to technology choices to achieve decarbonization targets (Gerres et al., 2019). Thus, we assess *solution alignment* to be 'high' if emitters have made substantial commitments in the form of taken investment decisions or commercialized projects in technologies prioritized by the national government, 'intermediate' if they have ambitions or formalized plans of applying technologies prioritized by government, and 'low' if they are not signalling interest in the prioritized technologies.

For all three dimensions, we assess the alignment of each emitter with government policy (low = 0; intermediate = 0.5; high = 1). We consider this a proxy indicator that allows for aggregation from emitter level to national level (see summary tables for each country in Appendix A) and supports comparison across the countries. Thus, we draw conclusions at the national level by considering the average degree of alignment of all 10 emitters (<0.33 = low; 0.33–0.66 = intermediate; > 0.66 = high).

3. The cases in focus – EPI characteristics

The size of EPI GHG emissions vary significantly between countries (Appendix Table B1). The UK, Netherlands and Germany have significantly larger emissions than the three Scandinavian countries, but in terms of share of national emission, the Netherlands, Sweden and Norway stand out with EPIs constituting between 22% and 26%.

In terms of sectors, iron and steel, cement, chemicals and refined petroleum production are the largest EPI emitters across the countries. Iron and steel industry emissions are particularly high in Germany, the UK and Sweden, due to the use of both fossil fuels and raw materials (i.e. coal as a reduction agent). The chemicals sector is the largest emitter in the Netherlands (due to the use of fossil fuels both as energy source and feedstock), refined petroleum production in Norway (stemming from various refining processes), and the cement industry in Denmark (emissions result from calcination of limestone and use of fossil fuels for heat). In addition to fossil emissions Sweden is also particularly characterized by large amounts of biogenic carbon emissions (Swedish Environment Agency, 2021) from the pulp and paper industry. These emissions are due to the process-internal combustion of biomass for heating purposes, which was introduced as the sector moved away from fossil fuels in the 1980s (Bergquist & Söderholm, 2016).

The industry's scope 2 emissions (i.e. indirect emissions from purchased energy) are low in the three Scandinavian countries due to the low-carbon electricity mix (in particular in Norway and Sweden) as well as on-site production of electricity and heat among main emitters. Conversely, scope 2 emissions are significant in Germany, the Netherlands and the UK due to the continuing significance of fossil fuels

[3]When assessing target and temporal alignment, we characterize cases where emitters are more ambitious than government policy as 'high alignment'. i.e. 'high alignment' does not require that emitters set exactly the same targets and with similar timeline as government policy, but that they at least are as ambitious as government policy.

Table 1. Decarbonization solutions for EPIs. Loosely based on Bashmakov et al. (2023), Bauer et al. (2022).

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 or 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 (utilization) 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 requires significant increase in electricity production, grid capacity, transport and storage solutions
Bio feedstock	Energy and/or resource input	All industrial sectors	Scalability and resource availability is a limiting factor in most cases, but can be significantly important when combined with other solutions
Energy efficiency	Energy input (reduced)	All industrial sectors	Important, but insufficient for net-zero emission as standalone solution

in these countries' electricity mixes (e.g. Berenschot, 2017). In this paper, we do not focus on scope 3 emissions (i.e. indirect up- or downstream emissions from activities not owned by the firm), but they are substantial, in particular in the refinery sector following from emissions that arise from the combustion of fossil fuels.

The share of total emissions from the largest emitters varies substantially by country, with the highest concentration levels in Denmark, Germany and Sweden (see Appendix B).

Several decarbonization solutions exist for EPIs, reflecting their heterogeneity. Some EPIs have multiple decarbonization options, while others have fewer. While energy efficiency has been high on the agenda for a long time already (due to, among other things, potential cost savings) (Bashmakov et al., 2023), it cannot contribute to necessary emission reductions (Bauer et al., 2022), and we consequently leave it out of the analysis. Instead, we focus on solutions both in energy and material inputs as well as end-of-pipe solutions. The main solutions and their key characteristics are listed in Table 1. Note that this overview is highly stylized. For example, the feasibility of different decarbonization solutions for cement production facilities may differ substantially depending on, for instance, their process set-up, potential for alternative energy access, distance to CO_2-storage opportunities, etc.

4. Alignment of industry strategy and government policy

4.1. Denmark

Denmark is one of the countries with a net zero target for 2050. Further, the Danish Government appointed in December 2022 has signalled an ambition to move the net zero target to 2045, but this is not yet implemented in legislation. Denmark also set an intermediate target of 70% emission reductions by 2030 relative to 1990 (the most ambitious of the analysed countries), but with no sector-specific targets for EPIs. Consequently, the 70% target is also guiding decarbonization efforts in EPIs (Regeringens Klimapartnerskab for Energitung Industri, 2020).

Five out of the ten top emitters have no net zero target (see Appendix Tables A1 and A2 for details), highlighting an *intermediate target alignment*. Furthermore, the timelines of emitters' emissions reductions are in most cases not following the reductions of the Danish government. Two emitters have set early net zero targets (2033 and 2035), indicating that they may also live up to the 70% reduction target by 2030, and one emitter has intermediate and long-term targets in line with the government's policy. However, of the remaining seven emitters, five have either no target at all or too unambitious timelines for both mid- and long-term targets. The last two emitters have reductions timelines that are too slow for the mid-term target. Consequently, the Danish case is characterized by *intermediate temporal alignment*.

In terms of technology options, CCUS and biogas are the main decarbonization technologies prioritized in Danish policy (Appendix C). Denmark has high levels of technology-specificity in its policies with significant funds allocated to these decarbonization options through technology-specific funding instruments. Comparatively few funds are set aside for hydrogen and other options in the context of decarbonizing EPIs. This is mirrored in the commitment of emitters (Appendix Tables A1 and A2): three emitters have either ambitions or plans for electrification, and hydrogen activity is restricted to one commercialized project. The prioritization of biogas is prevalent in both policy and industry strategy: three emitters have already implemented biogas, an additional has invested, and a fifth emitter has plans for investment. Conversely, interest in CCUS deviates; while CCUS is emphasized in policy, only two emitters have ambitions or plans to use CCUS. Overall, this leads to an *intermediate level of solution alignment*.

4.2. Germany

In 2021, Germany implemented a target of climate neutrality by 2045, upgraded from the previous 2050 target. The amended climate act also includes targets of 65% emission reduction by 2030 and 88% emission reduction by 2040, both compared to 1990. Additionally, the act includes sector specific (energy, industry, buildings, transport, agriculture and waste) emissions budgets, which specify annual GHG emissions reduction targets. For industry as a whole, the permissible annual emission budget is stipulated to 118 million tons CO_2e in 2030 (Federal ministry for the Environment Nature Conservation Nuclear Safety and Consumer Protection, 2021). This represents a 57.7% emission reduction compared to 1990, and thus somewhat lower than the economy wide target of 65% (German Environment Agency, 2023).

In terms of main EPI emitters, six out of ten have climate neutrality targets, suggesting intermediate target alignment (Appendix Tables A3 and A4). However, temporal alignment is intermediate or low for all emitters because no emitters have set timelines that align with policy. Temporal misalignment is due to differing intermediate targets, or different target years for climate neutrality. While three emitters have set climate neutrality targets that align with the 2045 policy target, their intermediate targets do not align with the policy targets. One emitter has set a lower 2030 target than policy and has no climate neutrality target. Three emitters have no stated emission reduction targets. Finally, three emitters have stated targets of climate neutrality by 2050, which temporally misaligns with the most recent policy. Overall, while a slight majority of emitters (6) have climate neutrality targets, which suggests *intermediate target alignment*, none have temporal targets that fully align with policy, which means the German case is characterized by *low temporal alignment*.

In terms of decarbonization solutions, hydrogen and electrification are the main technologies prioritized by the German government, with significant amounts of technology-specific support for, in particular, hydrogen. When it comes to CCUS, Germany stands out with a much less supportive policy framework as compared to other countries even if the government has recently signalled a more positive stance (Appendix C).

Seven of the ten top EPI emitters in Germany list hydrogen as a prioritized decarbonization solution suggesting some solution alignment with policy. Specifically, three actors have made investment decisions, another three have formalized plans for implanting hydrogen, and the remaining emitter has stated hydrogen ambitions. Germany's second prioritized decarbonization solution of electrification is only mirrored among one of the top ten emitters. CCUS is not a prioritized policy solution and only two emitters have listed CCUS as a prioritized solution. We thus see an *intermediate solution alignment* in the German case driven primarily by significant prioritization of hydrogen (and the contrary for CCUS) in both policy and industry strategy.

4.3. Netherlands

In 2019 the Dutch Parliament passed a new Climate Act that mandated a 49% reduction in GHG emissions in 2030 compared to 1990 and 95% by 2050 (Ministry of Economic Affairs and Climate Policy 2019; Government of the Netherlands no date). The Climate Act states that by 2050 both the electricity and the industry sector should be climate neutral. In the National Climate Agreement, 'Industry' encompasses waste incineration and both ETS- and non-ETS sectors. The main emission reductions in the Netherlands are expected (and needed) in the power sector, by expanding renewable energy sources (PBL Netherlands Environmental Assessment Agency, 2020). The Dutch Climate Agreement translates the Climate Act into sectoral agreements and aims at reducing industry emissions by 14.3 MT CO_2-eq (on top of an existing baseline trajectory by PBL) by 2030. Following the Climate Agreement, the entire industrial sector in the Netherlands needs to achieve a 59% GHG emission reduction by 2030.

Of the ten largest emitters in the Netherlands (Appendix Tables A5 and A6), five have a net zero or carbon-neutral target, whereas the other five have no clearly stated commitments for emission reductions. *Target alignment in the Netherlands is therefore intermediate*. In terms of temporal alignment, four emitters have stated decarbonization targets in the range of 20–40% by 2030 (or 2035 in the case of Air Liquide). The other six emitters either have no clearly stated decarbonization target at all, or only for 2050, or with unclear timeline. This means that *temporal alignment is low*.

The main solutions prioritized in Dutch policy are hydrogen, electrification/renewable energy and CCUS, supported in particular through the SDE++ (Stimulation of sustainable energy production and climate transition) scheme (Appendix C). Several of the ten largest emitters in the Netherlands state two or more prioritized decarbonization pathways, where the most prominent combination is CCS and hydrogen. Seven of the ten largest emitters show interest in hydrogen (of which two are explicit on green hydrogen), whereas only one emitter had made an investment decision. Two emitters refer to electricity/electrification and six to CCS, all mainly as ambitions. *Solution alignment between policy and emitters in the Netherlands is thus overall found to be intermediate*.

4.4. Norway

Norway aims for a 50–55% overall emission reduction by 2030 and seeks to achieve a 90–95% reduction and an ill-defined 'low-emission society' by 2050. Norway has no sector-specific targets for EPIs.

All of Norway's top ten EPI emitters target net zero emissions by 2050 (Appendix Tables A7 and A8). We thus assess the *target alignment as high*. However, only four facilities have facility-specific intermediate and 2050 targets – the other six falling under companywide net zero by 2050 targets. Two emitters target roughly zero emissions by 2030, one targets a 90% reduction by 2028, and another aims for a 50% reduction by 2030. In sum, four emitters exceed or align with Norway's target of 50–55% emissions reductions by 2030, while six fall short of that goal. In contrast, all emitters target net zero emissions by 2050, exceeding Norway's goal of 90–95% reduction. *Temporal alignment is therefore high*.

Norwegian policy prioritizes CCS and hydrogen, while increased electrification, based on domestic hydropower, is also seen as a key decarbonization solution in parts of the EPI (Appendix C). CCS has long been high on the political agenda, but substantial funding has also been allocated for hydrogen technology development and demonstration projects in most recent years. Six of the ten largest emitters show interest in CCUS (three facilities belong to the same company: Hydro, the aluminium producer). One emitter has invested, and construction of the CCS plant is underway. Among the other five facilities, engagement ranges from stated ambitions to formalized plans for utilizing CCS. One emitter has invested in green hydrogen, while another has a stated ambition to adopt low- and zero carbon hydrogen activities. Regarding other solutions, one has formalized plans regarding electrification, while the three others have stated ambitions. Two have plans for switching to bio feedstocks. Finally, one company is pursuing a new low-emission production process for aluminium production. Since only three plants have made concrete investments in government prioritized solutions, *solution alignment is considered intermediate.*

4.5. Sweden

The Swedish climate law sets a net zero emissions target for 2045 with an ambition to achieve negative emissions thereafter (Swedish Government, 2016). The target must be met by an 85% reduction of domestic emissions relative to 1990 baseline, but complementary measures (i.e. increased carbon uptake in the domestic LULUCF sector and non-domestic emissions reductions) can account for the remaining 15%. Sweden also has intermediate targets to reduce emissions by 63% (2030) and by 75% (2040) compared to a 1990 baseline. While the net zero emissions target for 2045 has broad political support (Swedish Climate Policy Council, 2023), the government currently evaluates the intermediate targets in light of recent EU policy developments (Hassler, 2023).

When it comes to the largest Swedish emitters, seven out of ten follow national or European policy by stating net zero emissions targets (Appendix Tables A9 and A10). We can thus conclude that there is a *high target alignment*. Two of the main emitters aim to reach net zero emissions in 2045, while three of them go even further, aiming to reach net zero emissions in 2040 or earlier. Notably, these companies produce steel, refined fuels and burnt lime, and thus represent three different EPIs. The remaining five aim to reach net zero emissions by 2050, have intermediate targets that are less stringent than national policy, and/or lack targets altogether. We can thus conclude that there is *intermediate temporal alignment*.

Concerning technology options, most policy instruments to support decarbonization in Sweden refrain from explicitly prioritizing among potential solutions (Appendix C). Thus, policy prioritization is operationalized at the level of government agencies and funding bodies when deciding on approving or rejecting applications for support. This implies that industrial strategies exert important influence on directionality (i.e. by proposing projects that public funding bodies can choose to support). Nevertheless, 80% of the public funding to date has been directed towards two main technology options: hydrogen and CCUS (with electrification as an important enabler) (Andersson & Hellsmark, 2022).

Regarding the efforts of main emitters, iron and steel producers focus heavily on hydrogen and have accordingly deselected CCUS as a route to net zero emissions. In contrast, companies in the cement and minerals industry see CCUS as the only viable technology option, but they do, however, already reduce emissions by using bioenergy and bio-based feedstock on a commercial basis. This also applies to companies in the refining industry, which have long produced various biofuels and currently aim to expand this part of their businesses. Though, one of them actively explores CCUS to reduce emissions further as well as to produce negative emissions. In the chemicals industry, the largest emitter focuses on transitioning to bio-based feedstock, while other chemicals producers, which do not qualify as 'largest emitters' in this paper, also explore CCUS applied to methanol production. Lastly, one of the largest emitters in the nonferrous metals industry focuses on electrification as well as increasing the use of recycled materials, while the other has neither ongoing decarbonization activities nor explicit strategies.

When assessing the solution alignment in Sweden, we assume that national policy prioritizes all technologies that constitute viable pathways to net zero emissions (i.e. we exclude energy efficiency, first-generation biofuels etc.). From this perspective, there is *intermediate solution alignment* because most main emitters have formalized plans or ambitions to decarbonize their operations. Hydrogen, electrification, CCUS and biofuels, are highlighted but few investment decisions have been taken.

4.6. UK

Decarbonization of the UK's EPI is primarily driven by the Climate Change Act from 2008 which was one of the first legally binding targets for decarbonization in the world (UK National Archives, 2008). It is based on interim targets set every five years, most recently in 2019 (Sixth Carbon Budget) which set a target of 78% carbon emissions reduction from 1990 levels by 2035. This target is in line with UK's national target of becoming Net Zero by 2050. To achieve this, the UK has outlined a plan in the Industrial Decarbonization Strategy (UK Department for Business Energy & Industrial Strategy, 2021) where they discuss how to achieve two-thirds reduction by 2035, and a 90% reduction by 2050. They propose offsets to mitigate the last 10% of emissions. However, they do not commit to these goals politically.

Eight of the ten top EPI emitters in the UK have set net zero targets by 2050 or earlier (2035, 2040 and 2045 respectively) suggesting a *high target alignment* when it comes to the national goal of net zero by 2050 (Appendix Tables A11 and A12). However, only one emitter has set a target (net zero by 2035) in line with the UK's 2019 Sixth Carbon Budget report with one other emitter coming close with a target of 65% reduction by 2030. This is categorized as *intermediate temporal alignment*.

Government policy in the UK focuses on CCUS and hydrogen as central technology options for industrial decarbonization. Both technologies are supported through designated policy schemes (Appendix C). Nine of the ten top industrial emitters have set at minimum an ambition to use CCUS as a mitigation tool. Of these, two have formalized plans to integrate CCUS while two others have made the decision to invest. When it comes to hydrogen, six out of the ten top industrial emitters have it listed as a strategy. Only two of these have made formal investment decisions. Thus, there is *intermediate solution alignment* in the UK.

5. Discussion

Table 2 summarizes the level of alignment across the countries. As evident, *target alignment* is relatively high with most emitters committing to decarbonization levels in line with their national policies, in particular in Norway where all ten emitters are in line with public policy. This highlights that variation in national GHG reduction targets does not result in radically different ambitions among emitters (e.g. comparing Sweden (ambitious national targets) and Norway (less ambitious national targets)). *Temporal alignment* is significantly more varied, with very low levels of alignment in the Netherland and Germany, and singularly high alignment in Norway. The lower temporal alignment is primarily driven by many emitters' lack of intermediate targets or intermediate targets that are significantly less ambitious than the national intermediate targets. This finding is in line with other recent analyses, which highlight that even firms committing to ambitious industry self-regulation initiatives focused on decarbonization demonstrate insufficient commitment to intermediate targets (Day et al., 2023; United Nations' High-Level Expert Group on the Net Zero Emissions Commitments of Non-State Entities, 2022). As highlighted by Rogelj et al. (2021), the lack of such milestones raises questions around the credibility of decarbonization efforts as well as the firms' commitment to contribute to intermediate reduction targets.

Solution alignment varies relatively little across the countries, with all six countries characterized by an intermediate level of alignment. CCUS, hydrogen and electrification are the three main prioritized decarbonization options by policy, with some differences between the countries (e.g. biogas prioritized in Denmark and CCUS not prioritized in Germany). The intermediate level of alignment reflects that emitters in general demonstrate interest in the decarbonization options prioritized by policy (and/or policy follows the interests of emitters), but the level of commitment is often low. This is particularly the case for CCUS where 24 out of the 27 emitters interested in CCUS are only at the level of plans or ambitions, with just three investment decisions taken so far. For hydrogen, nine out of 24 emitters have invested or already commercialized the technology. Thus, overall, the largest emitters have limited commitment to the main decarbonization options prioritized in national policies, and commitments mostly remain at the level of interest which do not necessitate significant financial investments.

The lack of alignment between national policies and industry is also important in relation to the EU. In 2023, the European Parliament approved additional key legislative elements of the 'Fit for 55' legislative package including an EU ETS reform and the inclusion of the new EU Carbon Border Adjustment Mechanism (CBAM) (European Commission, 2023; European Parliament, 2023). The EU's 'Fit for 55' legislative package is part of the wider European Green Deal strategy to achieve climate neutrality by 2050 and introduces a set of reforms to the trading system that are critical to the industry's future carbon footprint. Above all, the pace

Table 2. Summary of alignment across the cases.

	Denmark	Germany	Netherlands	Norway	Sweden	UK
Target alignment	Intermediate (0.5)	Intermediate (0.6)	Intermediate (0.5)	High (1.0)	High (0.7)	High (0.8)
Temporal alignment	Intermediate (0.4)	Low (0.15)	Low (0.25)	High (0.75)	Intermediate (0.4)	Intermediate (0.5)
Solution alignment	Intermediate (0.45)	Intermediate (0.5)	Intermediate (0.5)	Intermediate (0.55)	Intermediate (0.6)	Intermediate (0.6)

Figures note level of alignment from 0 (complete misalignment) to 1 (full alignment). See method section for details.

of phasing out the right to emit will increase significantly starting from 2026 and free allocation of emissions will end completely in 2034. The free allocation will be replaced by CBAM, with the aim of (in the same way as the free allocation) avoiding carbon leakage. CBAM entered a transitional phase in October 2023, initially applying to certain carbon-intensive imports like cement, iron and steel, aluminium, fertilizers, electricity and hydrogen. The scope of CBAM will eventually cover over 50% of emissions in ETS-covered sectors when fully implemented in 2026 and potentially all emissions included in EU-ETS by 2030, including polymers, diverse chemicals, etc. The lack of alignment simply implies that if national policies and industrial strategies do not keep pace with these EU-wide changes, industries could face challenges in adapting to the new regulations where carbon costs are increasingly factored into the price of goods.

Furthermore, our results should be considered in relation to important differences between decarbonization solutions, particularly when it comes to their level of maturity. Policymakers may, for example, prioritize technologies that have a long-term potential but remain at an early stage of development with low private investment possibilities. Policymakers and industrial firms might thus agree on the pathway towards net zero emissions, without this being reflected in investment decisions among large emitters. A case in point is CCS, where many EPI emitters have announced ambitions but few have made investment decisions (see e.g. Hieminga & Zhang, 2024 in addition to the analysis in this paper). However, as shown by our analysis, the main decarbonization solutions available for EPIs are sufficiently mature for firms to commit by making large investments, even if the development of new value chains, infrastructure and availability of renewable electricity may constitute a greater barrier in some contexts than others. The prevalence of mere ambitions and plans among many large emitters can accordingly not be explained by the immaturity of available options.

It should be noted that our analysis is focused upon pathways that align with continued economic growth and consumption. This is reflected in current industrial strategies and policy, where the aim of maintaining industrial activity is key. Novel policy measures to support industry decarbonization, such as carbon contracts for difference in Germany, are for instance accompanied by arguments of maintaining jobs and industrial activity (Federal Ministry for Economic Affairs and Climate Action, 2023). This mirrors a wider narrative of ecological modernization where clean technology development is part of the solution (Schreurs, 2020). However, the feasibility of relying on such narratives and associated technology-based pathways to achieve the 1.5°C Paris target is being questioned, and arguments for degrowth pathways are for instance proposed, albeit with a disclaimer of challenging political feasibility (Keyßer & Lenzen, 2021; Riahi et al., 2022). Similarly, the concept of sufficiency is being pitched as a novel way of organizing societies in alignment with planetary boundaries (Hayden, 2019). Such alternative pathways are however subject to radical political change, and misalignment of government and industry could be expected. If policy should start to involve such measures, the flexibility of our framework should allow for adjustments to include such alternative pathways.

In examining the alignment between national policy and industry strategy, we acknowledge that our assessments are limited by the information available as well as significant uncertainty regarding the actual implications of investments. One aspect of this is that emitters are not always clear on the baseline for their intermediate reduction targets or chose a contemporary baseline rather than the 1990-baseline used by governments. To exemplify, the largest Danish emitter Aalborg Portland has set a reduction target of 73% by 2030 relative to 2018 but verified emissions at the plant level are only available back to 2005 from the Danish Energy Agency making it difficult to assess if this target is actually in line with the Danish decarbonization target. Consequently, there is a risk that we overestimate the level of temporal alignment. A second aspect is that emitters frequently do not provide the size of emission reductions following from investments, thus making it difficult to evaluate the significance of investment decisions. Further, it might not always be clear to what extent investments by emitters will decarbonize their own industrial processes, as opposed to build production capacity for fossil free fuels and materials that can contribute to decarbonizing downstream industries (i.e. their customers). One example is the investment in blue hydrogen production at Essar Oil's Stanlow Refinery in the UK, which is partly motivated by a contribution to decarbonization of its own energy demand, and partly by a plan for selling hydrogen to downstream industries (Essar, 2021). Essentially, in this case, the decarbonization effects on the emitter's scope 1 and 2 emissions are impossible to predict at this point and will likely depend on market conditions for hydrogen when production is ready to commence.[4] Finally, the extent to which investment in the different technological options contribute to decarbonization also depends on whether they are displacing or complementing existing processes. An example of the former is Shell's plans to replace oil refining with green hydrogen production at their two German refineries (Shell, 2021), while an example of the latter is Esso Petroleum's plans of adding hydrogen production to their Fawley refinery in the UK, without any explicit plans of phasing out their existing production (ExxonMobil, 2021).

6. Conclusion

Focusing on the ten largest emitters from EPIs in each of the six Northern European countries of Denmark, Germany, Netherlands, Norway, Sweden and the UK, we aimed to better understand the GHG emissions reduction targets and prioritized decarbonization options set by government and industry. In turn, our ambition was to assess the alignment of decarbonization policy with industry strategy in terms of size of emission reduction targets (target alignment), the timeline of reduction targets (temporal alignment), and the prioritized decarbonization options (solution alignment). We find high target alignment, but substantially lower temporal alignment as EPI emitters are particularly reluctant to commit to intermediate targets that match the government set decarbonization timelines. Solution alignment is intermediate across all six countries as emitters generally pursue the decarbonization options prioritized in policy. But only at the level of ambitions or plans. Thus, the largest emitters demonstrate substantial interest in these decarbonization options, which is evident in their strategy documents, market communications and their participation in publicly funded research and development projects. However, the actual commitment to invest in these technologies is limited among main emitters, with some activities in hydrogen, but very few investment decisions or commercialized projects in CCUS and electrification. Partly, this may be a question of time lag between policy attention and industry responses (for example, CCUS policy is relatively recent in Denmark). Nevertheless, in some contexts, efforts have been ongoing for some time but with relatively limited impact. This suggests challenges with ensuring directionality that is based on a joint understanding between industry and government, which has been noted as key to succeeding with industrial decarbonization (Nilsson et al., 2021).

The decarbonization of EPIs and other hard-to-abate sectors presents a major governance challenge for policymakers due to, for example, the differences in the prevailing situations that impact decarbonization, and the variation in possible technological solutions (Bergek et al., 2023). To support policymakers in governing this challenge, we propose an evaluative perspective to assess the degree of alignment (in terms of targets, temporality and solutions) between national governmental policies and industrial strategies. We expect that a relatively high degree of alignment between these public and private decarbonization directions is conducive for the effectiveness of climate policies. We suggest that the proposed assessment can thus reveal insights regarding, for example, the foreseen feasibility of current national climate change mitigation policies, potential conflicts between public and private climate action, possible needs for changes in either national policies or industrial strategies, and the status and potential needs for improved public-private interaction.

The central policy recommendation following from our analysis is that governments should continuously survey alignment of their policy targets and prioritized decarbonization options with industry targets and activities. Where such alignment is low, more active policymaking that provides the support and incentives needed to make industry act in relation to both intermediate and end goals will be needed. This recommendation echoes a recent call by the Swedish Climate Policy Council (2024), which points to a meta-level policy recommendation, namely to ensure that the capacity to undertake these types of analyses are available at the national level, which is frequently not the case in European countries (Evans et al., 2021). Finally, while we focus on the national level in our analysis, collaboration across countries is central to the feasibility of many of the decarbonization options, illustrated by the German case where imports of hydrogen (and potentially export of CO_2 to foreign storage sites) are essential parts of the decarbonization puzzle. This demonstrates the importance of complementing attention to alignment between industry strategy and government policy

[4]An implication is that the analysis may overestimate the number of hydrogen decarbonisation investments in the refinery industry.

with attention to alignment across sectors and value chain segments (Mäkitie et al., 2022; Nykamp et al., 2023) that often go across national borders.

Finally, acknowledging the limitations of the current analysis, future research might expand on our national focus to take a multi-scalar approach to policymaking, with the aim of examining how domestic approaches interact with EU-level, as well as the alignment between industry strategy and decarbonization policy at multiple levels. Further, many of the main emitters included in the analysis are part of multinational firms with facilities in different countries. These actors are likely to test new solutions in one country, and deploy in other countries at a later stage, thus, a passive stance in one country can quickly be replaced by a large investment if trials in a neighbouring country succeed. This points to the importance of improving our understanding of such intra-firm dynamics, including variations between firms in terms of whether to pursue same or different decarbonization options at different plants.

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