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Directionality in transformative policy missions: The case of reaching net zero emissions in the Swedish process industry☆

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ABSTRACT

This paper proposes a directionality framework that highlights goal, sector and solution as key dimensions of transformative policy missions. The framework is used to investigate the directionality of process industry decarbonization in Sweden, by analyzing the orientation of projects supported by the major national funding program the 'Industry Leap' between 2017 and 2022. The results show that innovation activities (i) mainly aim to reduce fossil emissions rather than produce negative emissions, (ii) focus on the steel and chemicals industries, and (iii) engage mostly with carbon capture, electrification and hydrogen. This indicates that innovation activities are somewhat narrow and imbalanced, which suggests that policymakers should promote broader experimentation. The theoretical and empirical contribution of this paper supports academics, policymakers and other actors in understanding, evaluating and shaping the directionality of transformative policy missions.

1. Introduction

Climate change and other grand challenges cannot be met by efforts to increase the general innovation capacity of society, nor by the development and diffusion of individual technologies. Instead, there is a need for far-reaching transitions to more sustainable systems of production and consumption across the economy (Köhler et al., 2019). This involves a massive diffusion of novel technologies and practices as well as the phasing-out of existing systems that result in undesirable environmental impacts and socio-economic problems (Geels, 2002; Kivimaa and Kern, 2016; Rip and Kemp, 1998; Turnheim and Geels, 2013). Indeed, addressing grand challenges requires a clear and bold objective that can guide public and private actors in their efforts to mobilize resources, direct investment and coordinate stakeholders (Mazzucato, 2015).

Governments at different levels are therefore increasingly launching transformative policy missions that establish goals for the development of economic sectors and use various policy instruments to guide innovation accordingly (European Commission, 2018; Hill et al., 2022; OECD, 2022). In contrast to the scientific and technological missions of the last century, today's sustainability-oriented missions often involve several sectors, multiple interlinked problems and goals as well as a wide range of potential solutions (Janssen et al., 2021; Wanzenböck et al., 2020). Depending on the directionality of mission-driven innovation activities, developments may thus come to focus on different pathways towards realizing the overarching objective and in the end lead to different outcomes (Andersson et al., 2021).

Understanding the directionality of transformative policy missions is crucial to enable policymaking that strikes an appropriate balance between promoting breadth and depth of innovation activities, while engaging with the contestation that emerging collective prioritization necessarily entails (Stirling, 2009, 2011). Although the existing literature offers useful definitions, rationales and conceptualizations, there are few studies that analyze the directionality of innovation activities in relation to contemporary missions as they unfold (Haddad et al., 2022; Janssen et al., 2021). This should not come as a surprise given that (explicit) missions-oriented innovation policy is a quite recent phenomenon with limited, albeit increasing, practical application. Nevertheless, the lack of empirical research that can serve as a foundation for further conceptual development and support policymaking is salient gap in the literature.

In this paper, we address this gap with an analysis of the mission to achieve zero emissions in the Swedish process industry. This mission is a part of the overarching Swedish climate policy framework, which by law

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stipulates that domestic net emissions shall be zero by 2045 and that negative emissions shall be realized thereafter (Swedish Government, 2016). The Swedish territorial fossil emissions have been reduced with 33 percent since 1990, while the gross domestic product (GDP) has nearly doubled (Statistics Sweden, 2023; Swedish Environmental Protection Agency, 2023a). However, while this certainly represents progress, Sweden will not reach its climate goals with the current rate of emissions reduction (Swedish Climate Policy Council, 2023).

Reaching net zero emissions is challenging for most economic sectors, but arguably particularly difficult for the process industry (Energy Transitions Commission, 2018; Johnsson et al., 2020; Löfgren and Rootzén, 2021). The production of steel, cement, petrochemicals and other process industrial products, gives rise to large fossil emissions that are not only due to the need for high temperatures, but also to the chemical conversion of raw materials such as iron ore and limestone (Energy Transitions Commission, 2018; Swedish Environmental Protection Agency, 2023a). Actors in the process industry also rely on continuous and large-scale production processes to stay competitive, while facing long investment cycles and exposure to global markets (Löfgren and Rootzén, 2021; Nilsson et al., 2021; Wesseling et al., 2017). This creates a strong lock-in effect to existing technologies and raises high barriers-to-entry for new actors, which hinders transformative change.

The process industry is responsible for a growing share of the total fossil emissions in Sweden, since other economic sectors decarbonize more rapidly. In 2022, 18 Mtons of fossil emissions, originating mainly from the production of steel, heat, power, cement and refined fuels (Fig. 1), were included in the EU emissions trading scheme (EU-ETS), which accounted for approximately 40 percent of the total territorial emissions in Sweden (Swedish Environmental Protection Agency, 2023b). Besides fossil emissions, the combustion of biomass in the production of pulp, paper, heat and power gives rise to large and significant emissions of biogenic carbon (Swedish Environmental Protection Agency, 2023c). Although these emissions are accounted as a part of the land use, land use change and forestry (LULUCF) sector and not the process industry (Swedish Environmental Protection Agency, 2023d), they are still relevant for the mission addressed in this paper. Biogenic carbon capture and storage (bio-CCS) produces negative emissions, which are not only required in the long-term (i.e. after 2045), but also qualifies as a complementary measure that can be used to account for 15% of the emissions reductions needed to achieve net zero emissions by 2045 (Swedish Government, 2016). Although biogenic emissions certainly contribute to global warming, at least over the time period until 2045, they thus also represent an opportunity in relation to the Swedish climate goals.

To complement the EU-ETS and further promote the decarbonization of existing industries, production of negative emissions and development of new industries that enable the transition to net zero emissions, the Swedish Government recently launched the “Industry Leap” (Swedish Government, 2017). From its beginning in 2017 to the end of 2022, the Industry Leap granted approximately 2 billion SEK to research, development, demonstration and commercial introduction of new technologies and business models.[1] Together with other national and European policy instruments, and a generally increasing concern about the effects of climate change with a growing demand for low-carbon products, this injection of resources has resulted in different innovation activities within the Swedish process industry. However, while scholars have investigated challenges and potential policy interventions for reaching zero-emissions in different value chains (Kushnir et al., 2020; Löfgren and Rootzén, 2021; Mossberg et al., 2021), little is known about the extent to which these innovation activities address different sectors in the process industry, engage with the mitigation of fossil emissions as opposed to the realization of negative emissions (i.e. through bio-CCS), and promote different technical and social solutions.

The purpose of this paper is to build knowledge about the ongoing mission to decarbonize the Swedish process industry. Our objective is to investigate the directionality of innovation activities as it is expressed through projects funded through the Industry Leap. Drawing on a dataset with information about all projects granted funding between 2017 and 2022, as well as the official Swedish emissions inventory, we analyze the extent to which innovation activities focus on different pathways towards realizing the Swedish climate goals. This corresponds to a salient gap in the literature on transformative policy missions, which has to date mainly focused on conceptual and theoretical matters. Our analysis has direct relevance for Swedish policymakers that promote and shape industry decarbonization, but since Sweden was one of the first countries to implement legally binding climate goals, together with policy instruments such as the Industry Leap, the case may also support the development of mission-oriented policymaking in other countries.

The empirical investigation uses a directionality framework developed for the purposes of this paper. It proposes that goal, sector and solution are three defining dimensions of transformative policy missions, and thereby outlines a goal-sector-solution space in which directionality unfolds. We are thus inspired by the problem-solution space proposed by Wanzenböck et al. (2020) but add attention to directionality in the sectoral dimension and focus on goals rather than problems. This theoretical contribution may be useful for academics, policymakers and other actors with an interest in understanding, evaluating and shaping the directionality of transformative policy missions.

After this brief introduction, Section 2 reviews relevant literature, Section 3 introduces our theoretical foundation and Section 4 describes our research design. Section 5 then presents our analysis of directionality in the decarbonization of Swedish industry. Lastly, we discuss our findings in Section 6 and summarize our conclusions in Section 7.

2. Literature review

In the light of urgent sustainability challenges, the last decade has seen the emergence of novel approaches to innovation policy (Haddad et al., 2022). Rather than treating innovation as a means for economic growth and national competitiveness, these approaches highlight the role of government in shaping innovation to reach more or less specific objectives (Diercks et al., 2018; Schot and Steinmueller, 2018; Weber and Rohracher, 2012). In particular, increasing concern about climate change and other grand challenges has led governments at different levels to establish transformative policy missions that outline ambitious goals for societal development (Brown, 2021; European Commission, 2018; Hill et al., 2022; Larrue, 2021; OECD, 2022; UCL, 2019). However, this is neither sufficient to guide the development and implementation of mission-oriented innovation policy, nor to support other stakeholders in their efforts to navigate and promote an ongoing transition (Haddad et al., 2022; Karltorp et al., 2019). There is also a need to understand the collective, cumulative and complex characteristics of innovation activities oriented towards the mission at hand, in order to identify areas that should be targeted by policy interventions and private initiatives.

A useful theoretical foundation for building this understanding is the innovation systems literature. Scholars in this tradition highlight that innovation is contingent on interdependent and interacting heterogenous elements, including organizations, institutions and technologies (Bergek et al., 2008b; Cooke et al., 1997; Edquist, 1997; Malerba, 2002). Consequently, weaknesses and failures in the innovation process are often found at the network- or systems-level, rather than within single organizations (Edquist, 2011). To enable a dynamic analysis of weaknesses and failures, scholars focusing on technological innovation systems (TIS) have also developed a typology of system functions, which include processes such as knowledge development, market formation,

[1] 11.27 SEK = 1 EUR (2023-05-16).

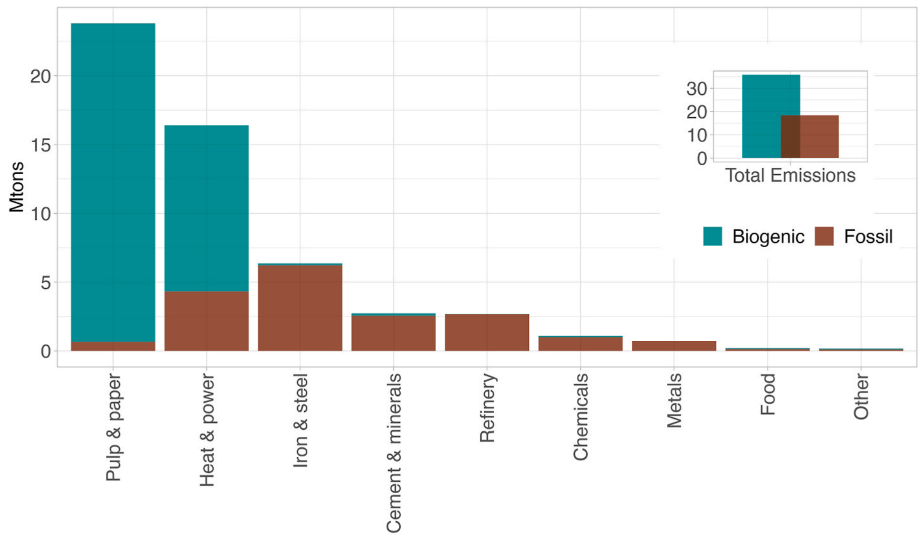

Fig. 1. Fossil and biogenic emissions from the Swedish process industry, including the heat & power sector, in 2022. Based on data from the Swedish Environmental Protection Agency (2023b,c).

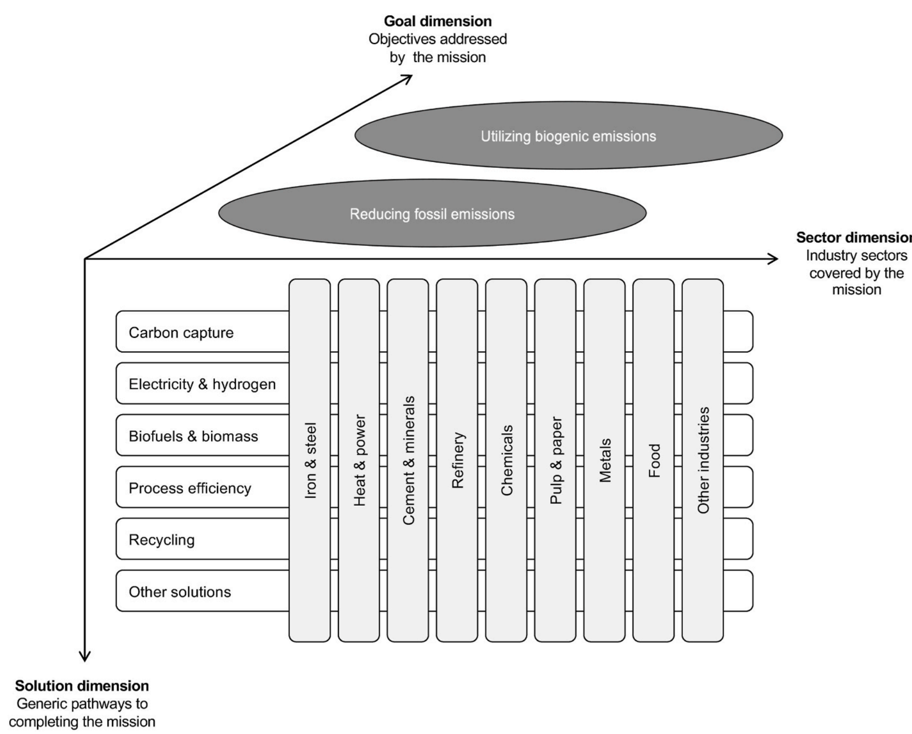

Fig. 2. Illustration of analytical framework used to investigate directionality.

legitimation and resource mobilization (Bergek et al., 2008a; Hekkert et al., 2007).

However, the innovation systems literature emerged in a context where analytical efforts treated innovation as a means to increase the economic output and competitiveness of nations (Freeman, 1988; Lundvall, 1992; Nelson, 1993). As a result, it often fails to account for the directionality of innovation processes, which is central to missions that seek to realize more specific societal objectives (Andersson et al., 2021; Yap and Truffer, 2019).[2] Scholars have therefore proposed an alternative approach that departs from mission-oriented policies, suggesting that these serve to reassemble innovation system structures associated with geographies, technologies and sectors, into so-called

[2] To some extent, the technological innovation systems framework accounts for directionality by focusing on the development and diffusion of specific technologies (Bergek et al., 2008a; Hekkert et al., 2007; Markard and Truffer, 2008), but the focus on emerging novelties still fails to fully capture the key characteristics of mission-oriented innovation (Ghazinoory et al., 2020; Hekkert et al., 2020).

mission-oriented innovation systems (MIS) (Hekkert et al., 2020). In the early literature that engages with this approach (Klerkx and Begemann, 2020; Klerkx and Rose, 2020; Sonnier and Grit, 2022; Wesseling and Meijerhof, 2023), it has also been argued that another central function of MIS, which is not captured by traditional typologies of functions in TIS, is to provide directionality to innovation activities, and thereby determine which problems that are prioritized and which solutions that become dominant as missions unfold (Wesseling and Meijerhof, 2023).

This idea is in line with a related stream of literature that focuses on the characteristics of transformative policy missions and mission-oriented innovation policy (Edquist and Zabala-Iturriagagoitia, 2012; Janssen et al., 2021; Kattel and Mazzucato, 2018; Mazzucato, 2018; Wanzenböck et al., 2020). In contrast to the centrally governed scientific and technological missions of the last century (Wittmann et al., 2021), transformative policy missions are associated with multiple interlinked problems and a range of potential solutions (Janssen et al., 2021; Wanzenböck et al., 2020). This also means that a wide array of stakeholders, with partly competing and conflicting interests, contest the viability and desirability of different pathways towards realizing the mission objective. Wanzenböck et al. (2020) frame this contestation process as operating in a problem-solution space (Brett et al., 2023; Bugge et al., 2021), where stakeholders may adopt different positions regarding which directions that should be prioritized and pursued. However, the problem-solution space has not (yet) been used as an analytical device to study the directionality of mission-oriented innovation activities.

Although the literature on MIS, transformative policy missions and mission-oriented innovation policy offers useful and inspiring theoretical ideas, it rests on a weak empirical foundation (Haddad et al., 2022; Janssen et al., 2021). In this paper, our ambition is to strengthen this foundation with an analysis of the directionality of innovation activities driven by the mission to decarbonize Swedish industry. We thus look into a central function of mission-oriented innovation systems (Hekkert et al., 2020), even though we refrain from elaborating on system dynamics and rather approach directionality from an outcomes perspective (Andersson et al., 2021).[3]

3. Theoretical framework

To capture key aspects of directionality, our analysis goes beyond the problem-solution space discussed in the received literature (Brett et al., 2023; Bugge et al., 2021; Janssen et al., 2021; Kattel and Mazzucato, 2018; Wanzenböck et al., 2020; Wittmann et al., 2021) and departs from three basic dimensions of transformative policy missions. First, there is a *goal dimension* in which missions have certain ambitions and aims. In contrast to general policymaking, however, the ambitions and aims of missions are concretized into a set of more specific, measurable and timebound objectives (Mazzucato, 2018; Robinson and Mazzucato, 2018). These may involve solving social and environmental problems, such as poverty, inequality, climate change and biodiversity loss, but also be oriented towards realizing potentials and reaping opportunities associated with an emerging technology field. Our conception of the goal dimension of missions thus modifies the problem-solution space to reflect the fact that missions may address both problems and potentials.

Second, there is a *sectoral dimension*. Here, a mission may address a narrowly defined sector (e.g. light road transport by car), a broadly defined sector (e.g. the transport sector as a whole) or even the economy as a whole). In the received literature, however, these different sectoral scopes have been largely neglected when discussing directionality and contestation (an exception is Wittmann et al. (2021)) where the sectoral dimension is made explicit in the discussion). Given that mission-oriented policymaking often targets a specific sector, industry, value chain or technology field, rather than the economy as a whole, this is quite surprising.

Third, and last, there is a *solution dimension* where missions involve alternative pathways towards completing the mission. These pathways are constituted by different ways to transform the sector in focus of the mission, in order to reach its defining objectives. As often pointed out in the received literature, complex missions can rarely be achieved by technical change alone (Brett et al., 2023; Bugge et al., 2021; Kattel and Mazzucato, 2018; Wanzenböck et al., 2020). There is also a need to transform organizations and institutions in the social domain. We therefore view pathways in the solution dimension as possible socio-technical transformations that contribute to reaching the objectives associated with missions.

Together with spatial and temporal characteristics, the dimensions outlined above can be used to define a particular transformative policy mission. In a sense, different delineations in the goal-sector-solution space represent different overarching directionalities that may be promoted by missions. But more importantly for the purposes of this paper, the goal-sector-solution space can be used to analyze the directionality of innovation activities as missions unfold.[4] Such analyses are highly relevant for policymakers and other stakeholders to transformative policy missions, partly because actual directionality may imply that some areas (e.g. a goal, an industry or a solution pathway) receive too little (or too much) attention, but also since it determines if, and how, a mission is completed (Andersson et al., 2021). In the next section, we describe how the goal-sector-solution space is operationalized for the purposes of this paper.

4. Research design

The empirical analysis in this paper concerns the mission to decarbonize the Swedish process industry. In relation to the goal-sector-solution space introduced in the previous section, this is a mission that aims to achieve net zero emissions by 2045 and negative emissions thereafter, covers a variety of industries with large emissions, and involves multiple and interlinked solution pathways (Swedish Climate Policy Council, 2023; Swedish Government, 2016). Below, we describe the approach, method and data used when analyzing this case.

4.1. Analytical approach

Our analytical approach is to decompose the mission in focus along the dimensions introduced in Section 3, using analytical categories developed for the purposes of this case. Starting with the goal dimension, the mission to decarbonize Swedish industry departs from a concrete, measurable and time-bound objective. This makes it different from other missions that may involve several interlinked and co-dependent objectives, such as ambitions to achieve “sustainability” or reduce “environmental impacts”. At the same time, however, it is possible to distinguish two different ambitions that are embedded in the mission: one goal is to reduce fossil emissions to reduce the negative climate impact of Swedish industry; another goal is to utilize biogenic

[3] The directionality of innovation activities can be approached from two complementary analytical perspectives. On the one hand, an investigation can strive to understand the formation of directionality, by analyzing how system dynamics shape the characteristics of innovation activities. Here, the structural-functional framework developed in the literature on technological innovation systems (Bergek et al., 2008a; Hekkert et al., 2007) offers a useful way to disentangle the innovation process and describe its dynamics. On the other hand, an investigation can focus on the outcomes of directionality, by analyzing the characteristics of innovation activities in relation to key dimensions of the socio-technical systems that are under transformation (Andersson et al., 2021).

[4] While we acknowledge that the definition and interpretation of missions evolve in tandem with the directionality of mission-driven innovation activities (Janssen et al., 2021; Wanzenböck et al., 2020), it is beyond the scope of this paper to discuss these dynamics.

emissions to produce a positive climate impact (i.e. negative emissions) from Swedish industry. When analyzing directionality, we therefore distinguish between innovation activities that target fossil as opposed to biogenic emissions.

In the sector dimension, the mission focuses on the Swedish process industry, which can be decomposed into several more specific industrial sectors, based on the type of products that are produced. While efforts may be relevant to the process industry as a whole, more applied innovation activities often aim to contribute to the decarbonization of a specific industry sector, and thereby target a specific part of the sectoral dimension. When analyzing directionality, we therefore distinguish between ten different target industries (Table 1). Except for a few modifications made for the purposes of this paper, this categorization is in line with the official reporting of Swedish emissions (Swedish Environmental Protection Agency, 2023a).[5] We have, however, added *Heat & power* as a target industry since it (i) gives rise to large-point source emissions of fossil carbon that must be mitigated to reach the Swedish climate goals, (ii) shares many solution pathways with the other industries, and (iii) has very large biogenic emissions that are key for the realization of negative emissions. It should also be noted that *Other industries* includes some industrial activities that enable national and global decarbonization, such as the production of electric drivetrains and batteries. As result, innovation activities that target industries in this category may be oriented towards stimulating new industries rather than reducing emissions (in this particular sector).

In the solution dimension, lastly, the mission involves multiple interlinked solutions that have both technological and social characteristics. While it is difficult, if not impossible, to decompose these into a mutually exclusive and collectively exhaustive categorization, it is possible to identify a number of generic solution pathways with relevance for the goals and sectors associated with the mission (Bataille et al., 2018; Bauer et al., 2022). When analyzing directionality, we distinguish between six such solution pathways (Table 2). These are mainly based on the extant literature, which generally highlights the importance of new production technologies such as increased process efficiency, carbon capture and storage (CCS), electrification, transitions to hydrogen, and increased use of biomass (Bauer et al., 2022; Energy Transitions Commission, 2018; Wesseling et al., 2017). We have, however, made some modifications to this line of thinking. To begin with, we refer to *Carbon capture* rather than CCS, to also include carbon capture and utilization (CCU). Second, we treat *Electricity & hydrogen* as a compound category, since the use of these energy carriers is strongly interrelated and addressed jointly by many innovation activities. Third, we refer to *Biofuels & biomass* to highlight that biomass may contribute to emissions abatement by both replacing fossil fuels and raw materials. Fourth, we use *Process efficiency* to refer to emission reductions realized by a more efficient way to use existing technologies or by introducing innovations with the purpose of reducing costs in combination with improving energy and resource efficiency. Fifth, we add *Recycling* to capture decarbonization based on the development of recycled material flows that can offset the use of virgin raw materials. In addition, we use *Other solutions* to refer to a range of alternative technical and social solutions. These include the development of alternative products that replace existing fuels and materials (e.g. new lignin-based materials for replacing steel in the automotive industry or new types of binders for making concrete), as well as downstream transformations that reduce or eliminate the demand for fuels and materials.[6]

Table 1
Categories used to distinguish target industries.

Target industry	Description
Pulp & paper	The production of paper and board from biomass, including printing activities.
Heat & power	The production of district heating and electric power through the combustion of waste, biomass or fossil fuel.
Iron & steel	The production of iron and steel, including related mining activities.
Cement & minerals	The production of cement, lime and other minerals.
Refinery	The production of fuel from fossil oil and gas or renewable alternatives.
Chemicals	The production of chemicals.
Metals	The production of copper, aluminum and other non-iron metals.
Food	The production of foodstuffs.
Other industries	The production of wood, electronics, buildings and other products, including non-iron mining. Notably, the category includes industrial activities that enable national and global decarbonization, such as the production of electric drivetrains and batteries.

Table 2
Categories used to distinguish solution pathways.

Solution pathway	Description
Carbon capture	Capturing, transporting, and utilizing or storing carbon emissions from production processes.
Electricity & hydrogen	Using electricity to replace fossil fuels and hydrogen to replace fossil fuels or raw materials in production processes.
Biofuels & biomass	Using biofuels and biomass to replace fossil fuels and raw materials in production processes.
Process efficiency	Increasing the energy or materials efficiency of production processes.
Recycling	Replacing the use of virgin raw materials in production processes with recycled material flows.
Other solutions	Other technical and social solutions that reduce emissions, for example (radically) different production processes, alternative products that replace existing fuels and materials, as well as downstream transformations that reduce or eliminate the demand for fuels and materials.

The resulting analytical framework is illustrated in Figure 2. It distinguishes between innovation activities that target fossil and biogenic emissions in the goal dimension, ten different industries in the sector dimension, and six pathways in the solution dimension. These categorizations serve as separate perspectives from which directionality can be observed and analyzed, but may also be combined to, for example, highlight which solution pathways that are in focus of efforts to decarbonize specific industry sectors.

4.2. Method and data

Our analysis builds on a dataset with information about all projects funded through the Industry Leap between 2017 and 2022.[7] Although mission-oriented innovation activities are not limited to the projects that receive funding by the Industry Leap, there are several reasons to

[5] We have chosen to include emissions related to iron mining in the category 'Iron & steel', since there are strong networks and joint activities among companies that mine and produce iron. This is different from the official emissions inventory, which includes all mining activities in the 'Other' category. In addition, we simplify the labels of some categories.

[6] Any innovation in production technology has consequences for what type of products and services that are produced further downstream. For example, introducing different types of biomass to a refinery process changes not only the process itself, but may also result in new products, such as E85, RME and HVO100, that may or may not require downstream changes in terms of fueling infrastructure and vehicles. However, fully tracing these effects would be overly complicated. Our analytical framework rather focuses on highlighting the difference between solutions that take the general idea of the existing product and its market applications for granted, and those that question and challenge established value chain structures.

[7] The dataset was obtained from the Swedish Energy Agency, which is the government agency responsible for granting project funding.

consider them a good indicator when analyzing directionality. To begin with, the Industry Leap is a major national policy instrument that specifically focuses on development, demonstration and scale-up projects oriented towards industry decarbonization. While some relevant activities might receive funding through other policy schemes, it is therefore likely that most relevant projects, co-funded by public agencies, are covered by our dataset. In addition, it is reasonable to believe that the overall orientation of innovation activities carried-out without public funding, and thus not captured by our dataset, is in line with the projects included in the Industry Leap. This argument is supported by the observation that the organizations responsible for most of the current emissions from the Swedish process industry do in fact participate in Industry Leap projects (Fig. 3).

For each project funded through the Industry Leap, the dataset provides information about participating organizations, granted public funding, required co-funding by participating organizations as well as a summary of purpose, aims and planned activities. The first step in our analysis was to combine the dataset with the official Swedish emissions inventory (Swedish Environmental Protection Agency, 2023b,c), to link each participating organization to their reported emissions.

The second step was to extend the dataset by assessing the aims and activities of each project. We began by inductively grouping the projects (i.e. without using pre-constructed categories) in different topics with respect to their technological orientation, and then categorized each group of projects in relation the solution pathways outlined by our analytical framework. A few projects oriented towards system-level studies of policy, finance and marketing could not be related to specific pathways and were instead labelled 'Not applicable'. We then used the initial inductive grouping to identify focus areas within each solution pathway. For example, within Electricity & hydrogen, projects target underlying measures such as (i) creating hydrogen storage capacity, (ii) enabling hydrogen production, (iii) using hydrogen for process heating or (iv) as a process input as well as using (v) electricity for process heating and (vi) digitalizing process operations. After that, we categorized each project with respect to the goal and sector dimensions in our analytical framework. Some projects address both fossil and biogenic emissions, for example by targeting emissions from the combustion of household waste (which has both fossil and biogenic content) in heat and power plants. These were labelled 'Mixed' in the goal dimension. Other projects promote decarbonization in several industry sectors, for example by developing methods for capturing carbon that can be applied to any large emission source. These were labelled 'Multiple' in the sector dimension.

The assessments which resulted in the project categorization are based on the project summaries in the original dataset and both authors were involved in the process. Our approach when assessing the projects was to focus on the purpose, rather than specific characteristics, of planned research, development and demonstration activities. For example, projects that involve electrification of process technology to enable carbon capture and storage, were seen as promoting Carbon capture as a solution pathway.

The third and final step was to wrangle, analyze and visualize the dataset in line with the techniques described by Wickham and Grolemund (2017) and Wickham (2016) using the software R. This enabled us to investigate directionality by observing the number and total budget of projects that address different goals, sectors and solutions, and in the end to produce the results presented in the next section. Notably, the analytical procedure underlying the results can be described as abductive, in the sense that categorizations have been developed by iterating between theory on innovation and sustainability transitions, empirical insights from the extant literature and our case-specific dataset (Dubois and Gadde, 2002).

5. Results – the directionality of Swedish process industry decarbonization

Using the approach outlined in the previous section, we now investigate the directionality of Swedish process industry decarbonization by analyzing the orientation of projects funded through the Industry Leap. Our overarching results are summarized in Fig. 4, which decomposes the total budget of projects co-funded by the Industry Leap in relation to target emissions, target industries and solution pathways in the goal-sector-solution space.

Starting with the sectoral dimension, our results highlight that innovation activities have a strong focus on decarbonization in the Iron & steel and Chemicals industries, which make up 45% and 33% of the total Industry Leap budget (Fig. 4). We also see that significant innovation activities target Other industries. Notably, most of these efforts focus on promoting the production of electric drivetrains, which may contribute to reducing emissions in the transport sector. Furthermore, Cement & minerals, Pulp & paper, Heat & power and Metals receive significant investment, while Refinery and Food hardly receive any attention at all. There are also projects that target multiple industries at the same time, which could potentially promote important cross-sectoral learning and infrastructure. However, with a few important exceptions, including the build-up of a common infrastructure for transport and distribution of captured carbon, cross-sectoral projects mainly concern policy studies and early-stage knowledge development about carbon capture technologies.

In the goal dimension, innovation activities mainly address the need to reduce fossil emissions. Projects that target this part of the mission make up as much as 90% of the total Industry Leap budget (Fig. 4). This should not come as a surprise given that reducing fossil emissions is the most salient, and possibly urgent, part of the Swedish climate goals. Also, the Industry Leap was at first not open to projects that address the need to produce negative emissions. Nevertheless, our results show that there are innovation activities that target biogenic emissions through the development of bio-CCS in the Heat & power and Pulp & paper industries. In addition, some projects target mixed emissions, by engaging with generic knowledge development about carbon capture (that can be applied to both biogenic and fossil emissions) and waste incineration. In this context, it could be argued that biogenic emissions ought to receive more attention given their magnitude (Fig. 1), their climate impact over long time scales, and the need to produce negative emissions to complete the mission.

In the solution dimension, our results show that Electricity & hydrogen and Carbon capture strongly dominate innovation activities, making up 80% of the total Industry Leap budget (Fig. 4). We also see that Recycling receives less but significant investment. However, Biofuels & biomass, Process efficiency and Other solutions receive much less attention, accounting for less than 4% (most of which is in fact oriented towards new industries that promote electric drivetrains). It is thus clear that innovation activities focus heavily on technological solutions that mainly address production processes, while alternative products and market transformations receive much less attention. To some extent, this is expected given that the Industry Leap is mainly focused on transitioning existing industry towards zero emissions. But it nevertheless indicates a certain imbalance, since it cannot be ruled out that radically different fuels and materials, combined with reduced or eliminated market demand, are more desirable pathways towards zero emissions.

To provide a more detailed view of our results, Fig. 5 illustrates the size of individual projects in relation to the goal-sector-solution space. In addition, Fig. 6 decomposes the total Industry Leap budget in relation to focus areas within each solution pathway and target industries.

This shows that Carbon capture receives the most attention in terms of the number of projects. As many as 70 out of 120 projects larger than 1 MSEK focus on Carbon capture (Fig. 5). The majority of these target biogenic emissions (36 projects) and are generally quite small with a

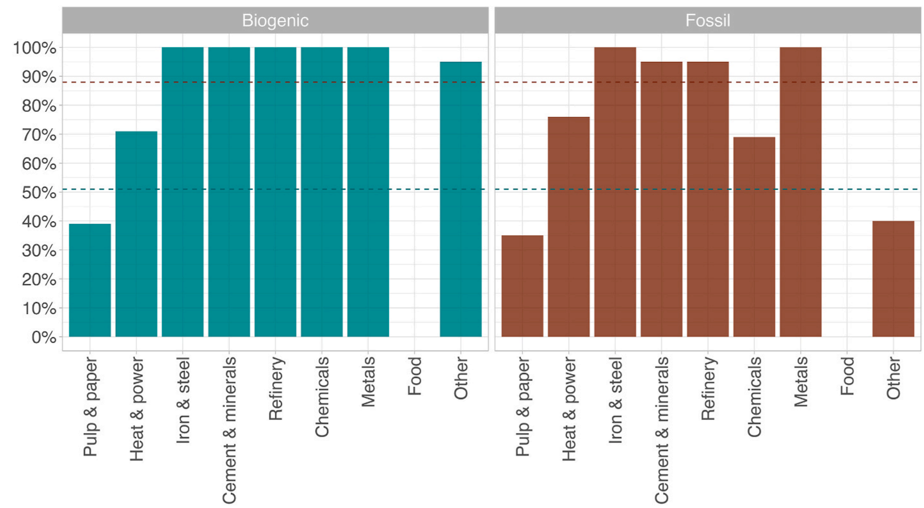

Fig. 3. Share of total process industry emissions originating from organizations participating in projects funded by the Industry Leap. In total, participating organizations are responsible for 86 percent of fossil emissions and 49 percent of biogenic emissions. Note that these figures are not adjusted to reflect the participating organizations' level of commitment (e.g. in terms of co-funding).

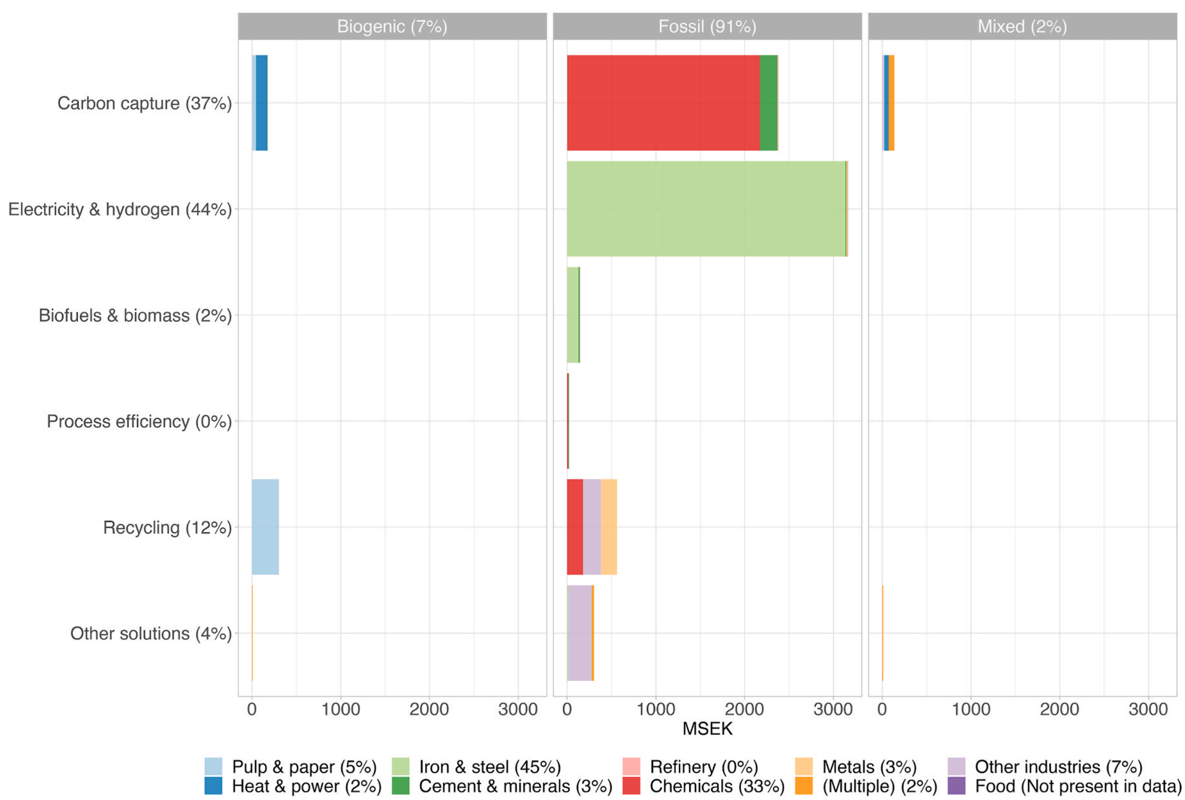

Fig. 4. Total budget of projects co-funded by Industry Leap (MSEK and percent) by per target emissions, target industries and solution pathways in the goal-sector-solution space.

focus on developing and implementing bio-CCS in the Heat & power and Pulp & paper industries. In contrast, Carbon capture projects that target fossil emissions (12 projects) are associated with the Chemicals, Cement & minerals and Refinery industries. Notably, one project in the Chemicals industry, which aims at capturing fossil process emissions and use them as feedstock in the production of methanol, is significantly larger than the rest. In addition, there are many projects that target both fossil and biogenic emissions at the same time (i.e. Mixed emissions) (22 projects). These concern the creation of common infrastructure, generic knowledge development as well as the development of CCS solutions for atmospheric carbon and emissions from waste incineration within Heat & power. Within the Carbon capture pathway, innovation activities thus engage with a wide design space, both in terms of more specific technological focus areas as well as target emissions and target industries.

Electricity & hydrogen is the focus of 24 projects. Both the largest and most of these are associated with the Iron & steel industry (18 projects), where leading actors have formed an alliance that aims to transition to fossil-free steel based on hydrogen. This alliance is involved in most projects and a wide range of focus areas are covered, ranging from digitalization of process operations and electrification of process

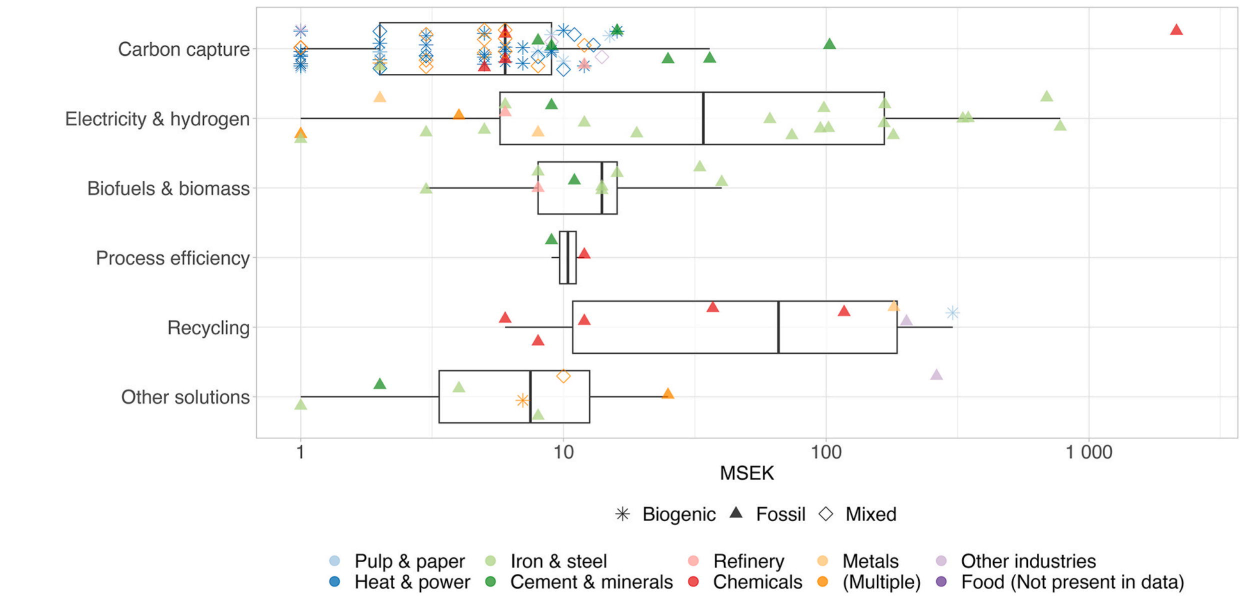

Fig. 5. The size (MSEK) of individual Industry Leap projects by target emissions, target industries and solution pathways in the goal-sector-solution space. Only projects larger than 1 MSEK are included (n = 120).

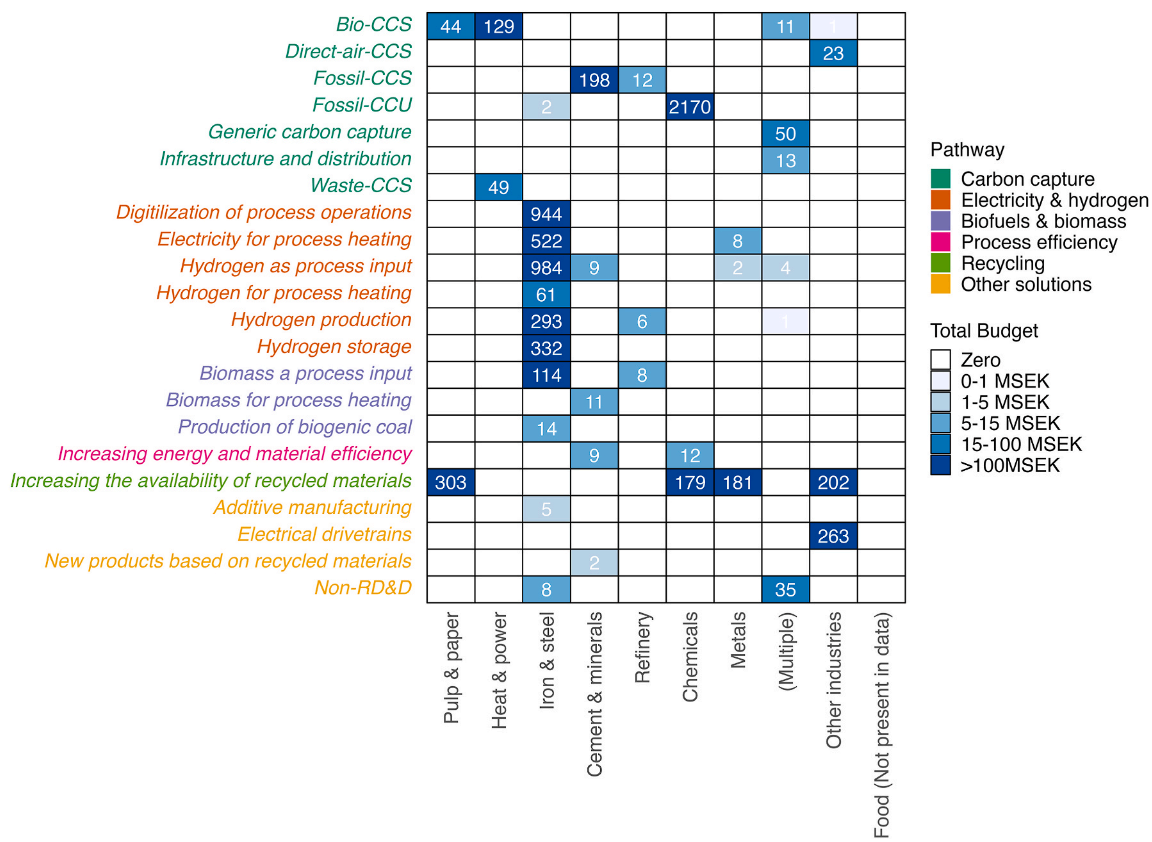

Fig. 6. Total budget of projects co-funded by Industry Leap (MSEK) by focus areas within solution pathways and target industries.

heating to various sub-processes involved in the use of hydrogen as a reduction agent (production, storage and use). What is perhaps somewhat surprising is that there are no projects that explicitly target hydrogen distribution (c.f. Carbon capture). Meanwhile, we also see that Electrification & hydrogen is an important solution pathway in other industries as well, including Cement & minerals, Metals and Refinery. However, in these industries, there are only single projects that are narrowly focused on hydrogen production and specific use cases. Several solutions are thus being developed within Electricity & hydrogen, but the activities so far are mainly concentrated to the Iron & steel industry.

Biofuels & biomass is addressed by 9 projects. Here as well, the most and the largest projects are associated with the Iron & steel industry (7 projects). These focus on the use of biomass as a process input as well as the production of biogenic coal. Increasing the use of biomass is also explored as a solution in the Cement & minerals industry for replacing coal in process heating, and in the Refinery industry for replacing fossil oil with different types of biobased oils. It should be noted that there are surprisingly few projects within the Refinery industry (given that biomass is one of few available solutions) and also that no projects focus on bioplastics in the Chemicals industry.

Process efficiency is only addressed by 2 projects. These focus on increasing energy efficiency through new production methods in the Chemicals industry and increasing material efficiency by implementing new measurement techniques in the Cement & minerals industry.

Recycling is the focus of 8 projects. Most of these target fossil emissions in the Chemicals industry, by introducing thermochemical plastics recycling and thereby decreasing the use of fossil feedstock (5 projects). However, the largest projects target Metals (recycling of aluminum), Pulp & paper (recycling of cartons used for liquids) and Other industries (recycling of batteries). Projects within Recycling thus focus on increasing the general availability of recycled materials as well as using recycled materials as a process input, thus substituting the use of virgin materials from fossil or bio-based resources.

Lastly, there are 7 projects that engage with Other solutions. The largest one targets the development of a new production process for electrical drivetrains, and thus promotes an enabling industry. Two other projects concern the development of additive manufacturing technology in the Iron & steel industry. The fourth project focuses on developing alternative binders in the Cement & minerals industry, which requires a new type of production process, depends on many complementary investments and would take significant time and effort to develop.

6. Discussion

The results of our analysis suggest that the directionality of process industry decarbonization in Sweden is somewhat narrow and imbalanced. Important tasks for policy could therefore be to promote broader experimentation that covers additional parts of the goal-sector-solution space. To begin with, this relates to the observation that directionality favors innovation in production technology, while few innovation activities engage with ideas that radically rethink the core products and even fewer develop technologies, business models and behaviors that may reduce the demand for both fuels and materials. The development of new production technologies is of course relevant and can be an effective strategy when an industry is dominated by a few firms and factories with large emissions (Bergek et al., 2023).[8] However, this also implies that incumbent actors take on central roles in the decarbonization process, often with little competition from new entrants in existing value chains and/or radically different modes of production and consumption. Since variety and competition are strong drivers for industrial change (Abernathy and Utterback, 1978; Christensen, 1997), more policy support to innovation activities that focus on rethinking core products and reducing the demand for fuels and materials could certainly be called for. This would put more pressure on incumbent actors that operate on mature markets with high entry barriers (Karltorp et al., 2019; Löfgren and Rootzén, 2021) to accelerate their efforts to develop new production technologies. In addition, it would enable the exploration of alternative solutions that may in the end turn out to be more desirable ways to achieve net zero emissions. This is in line with research by Kanger et al. (2020) and Lazarevic et al. (2022), who highlight the need for a multifaceted approach to influencing incumbent actors and stimulating transformative change.

Another observation that reveals the narrow and imbalanced directionality is that experimentation within industry sectors generally engages with relatively few solutions. In the iron and steel industry, for example, innovation activities are strongly focused on hydrogen-based steel production, even though there is quite broad experimentation within this particular solution pathway. Hence, if this decarbonization strategy – for one or the other reason – would fail, it would take many years to develop alternative solutions. Consequently, the Swedish climate goal would be seriously jeopardized since the production of iron and steel accounts for as much as ten percent of national emissions. The situation is slightly different in the chemicals industry, where innovation activities focus on both capturing and using carbon emissions and plastics recycling. This strategy creates more variation by incorporating different solution pathways, but at the same time there is less variation observed within each pathway. Also, although carbon capture and recycling are important steps towards reduced emissions, it is only in combination with electrification and/or increased use of biomass that net zero emissions can be reached. Notably, these latter solutions are not the focus of any innovation activities funded through the Industry Leap.[9] Additional examples of industries that exhibit limited variation across and within solution pathways are heat and power production and cement production, which almost exclusively focus on, and depend on, CCS.

From a societal perspective there is a significant risk with narrow directionality. Previous research has shown that experiments often fail for reasons that are beyond the control of policymakers and project owners (van der Panne et al., 2003). It is therefore key to strive for varied innovation activities that offer some level of redundancy. Variation within specific solution pathways may also be important to enable complementary investments that are required to actually reduce emissions. For example, realizing CCS requires not only technological innovation at the plant-level, but also an expanded power grid (to enable related electrification) as well as infrastructure for carbon transport and storage. In our study, we find surprisingly few efforts to develop and scale up this type of common and complementary infrastructure. As suggested in the literature, the investments needed are associated with significant uncertainties and therefore fall into a difficult grey zone of what national policymakers and individual project owners can influence (Bergek et al., 2023).

In general, however, it is difficult for policymakers to stimulate variation when key actors have adopted a specific strategy and are unwilling to experiment with alternative solution pathways. The cost of exploring several new solution pathways at the same time also needs to be taken into consideration, particularly since both Swedish and global climate goals call for rapid and large-scale deployment of solutions in a short timeframe. One way to, at least partly, address these challenges is to develop strategies focused on learning across industries and solution pathways, for example around key enabling technologies (Nikhil et al., 2022). We can also observe the ongoing development of several such strategies in Sweden, covering areas such as electrification (Swedish Government, 2022), bio-CCS (Swedish Energy Agency, 2021a) and hydrogen (Swedish Energy Agency, 2021b). At the same time, strategies are still lacking for the use of biomass, for other variations of carbon capture than bio-CCS, as well as for recycling and other downstream solution pathways. This may become a problem in the long run, not least when it comes to the use of biomass, which is a limited and contested resource with relevance for the decarbonization of several sectors (Bataille et al., 2018; Berndes and Magnusson, 2006). While our results thus suggest that policymakers should take a more active role in the development of cross-sectoral decarbonization strategies that include solutions along the entire value chain, a key question that remains is the appropriate technological scale at which to formulate such strategies. As pointed out in the literature, there may be trade-offs between strategies that realize synergies between broad pathways (e.g. carbon capture and

[8] Indirectly, implementing new production technologies may, as discussed in Section 2, also imply that new products are developed.

[9] However, we know from personal communication with industry representative that it is being discussed but due limited capacity in the electricity grid in the West Coast of Sweden any decisions towards electrification is put on hold.

biomass) as opposed to more narrowly defined solutions (e.g. bio-CCS and bioplastics) (Hillman and Sandén, 2008; Schmidt et al., 2016).

It is also clear that Swedish industry sectors have progressed at quite different paces, with the steel industry taking a clear lead in the decarbonization process. The slower progress observed in other industries can have several explanations that go beyond the scope of this paper to explore in full. It should be noted, though, that there are purely technical factors at play. Current blast furnaces used in Swedish steel production must soon be replaced due to old age, and when making key investments with a lifespan of 60–80 years, industry actors want to avoid being locked-in to old technology (such as coal fired blast furnaces). Another possible explanation is that efforts are driven by demand and offtake contracts from customers (such as the automotive industry) and increased competition from new actors interested in producing fossil free steel (Kushnir et al., 2020). This situation stands in stark contrast to, for example, the cement industry, where there is not only an absence of financing by customers, but also a general lack of competition. The cement market in Northern Europe is dominated by a single firm whose development efforts are centered in other countries such as Norway and Belgium (Dahlström, 2015; Karltorp et al., 2019). Hence, even though activities are undertaken in Sweden, it is not until trials in other countries are completed that CCS will be applied to Swedish cement production.

7. Conclusions

This paper set out to investigate the directionality of Swedish process industry decarbonization as it is expressed through projects funded through the Industry Leap. Our results show that innovation activities (i) mainly aim to reduce fossil emissions rather than produce negative emissions, (ii) focus on the steel and chemicals industries, and (iii) engage mostly with carbon capture, electrification and hydrogen. This indicates that innovation activities are somewhat narrow and imbalanced, which suggests that Swedish policymakers should promote broader experimentation.

Given that Sweden was one of the first countries to implement legally binding climate goals and related policies such as the Industry Leap, our results also bring important insights for the ongoing development of mission-oriented policymaking in other countries. In particular, the analysis highlights the importance of monitoring and evaluating the outcomes directionality, to enable policy interventions that shape mission-oriented innovation activities according to context-specific goals and pre-conditions.

In reaching these results, the paper has addressed the need for a stronger empirical basis on which to conceptualize and practically promote transformative policy missions (Haddad et al., 2022; Janssen et al., 2021). Moreover, it has introduced and illustrated an analytical framework that shows how directionality can be analyzed in relation to goal, sector and solution as three defining dimensions of transformative policy missions. This corresponds to a fine-tuning of the problem-solution space suggested by Wanzenböck et al. (2020), which brings more attention to directionality in the sectoral dimension as well as a focus on goals rather than problems. Since problems and solutions play out differently in different sectors, and goals may be associated with not only problems but also potential, this illustrates a useful approach to monitoring and evaluating the outcomes of directionality (Andersson et al., 2021).

Although our analysis has generated important findings, it should be acknowledged that our method, which relies on data about publicly funded projects within the Industry Leap, is associated with two main limitations. First, our dataset only covers a short time period in relation to the long duration of transition processes. Therefore, we are only able to present a snapshot of directionality in the goal-sector-solution space, rather than a view of the actual results of innovation activities. Second, and more importantly, there are numerous innovation activities that are not co-funded through the Industry Leap. This means that some parts of goal-sector-solution space may receive more attention than our results suggest. For example, the EU Innovation Fund (European Commission, 2023) has funded projects in Sweden and their activities are only partly captured by our dataset. The Industry Leap was also first designed with existing industries in mind, even though it has since been broadened to include emerging industries as well. As a result, innovation activities that, for example, focus on new products may occasionally fall outside the scope and, in theory, be pursued through other programs. Nevertheless, and as discussed in Section 2.3, we maintain that the characteristics of projects within the Industry Leap gives a valid, although by no means perfect, representation.

Lastly, the paper suggests several avenues for future research. While our results have generated the implications and suggestions discussed in the previous section, there is a need for further analysis to formulate more complete recommendations to Swedish policymakers. Such efforts should look beyond the outcomes of directionality and analyze the dynamics which shape innovation activities. This is likely to involve a broader empirical investigation, which accounts for projects, initiatives and policies outside the realm of the Industry Leap. Moreover, future research should engage with other geographies, sectors, solutions and goals. Indeed, there is certainly a need to further strengthen the empirical foundation of mission-oriented policymaking by quantifying, comparing and analyzing directionality, from both a dynamics and outcomes perspective, over time and across different contexts. In addition, future studies should investigate the role of firms in transformative policy missions. The increasing use of mission-oriented innovation policies rapidly alters the context in which firms operate and research is needed to inform the development and implementation of sustainable business strategies. In the end, we hope that the analytical framework and empirical findings presented in this paper can serve as a foundation and guide to such endeavors.

CRediT authorship contribution statement

John Andersson: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Hans Hellsmark:** Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, 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.

Data availability

Data will be made available on request.

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