THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Mission-oriented policies for Sustainability Transitions

Lessons from the Nordic industry transformation

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Abstract

Grand societal challenges, such as climate change and economic justice, are a key priority of public policy agendas. Mission-oriented policies have become a popular approach among policymakers worldwide to address such challenges. The ability of missions to provide a clear, focused framework makes them particularly attractive for societal challenges, where many stakeholders are involved, uncertainties and complexities are manifold, and diverse options and pathways may be pursued. However, so far, existing work provides little insight into the role of policies in societal missions nor offers sufficient guidance on how policy processes and policy mix design can be better aligned to achieve missions.

Grounded in the sustainability transitions literature, this thesis aims to improve the understanding of the role that policymaking plays in achieving societal missions. The thesis develops an analytical framework which extends the innovation systems approach by linking policymaking to the direction and dynamics of innovation, production, and consumption patterns. Using this analytical framework, the thesis studies three cases in the historical and ongoing transformation of the Nordic process industries. The Nordic countries have had implemented policies with an implicit mission-orientation over an extended period, and thus, should offer relevant insights into the role of mission-oriented policymaking in sustainability transitions.

The thesis contributes to studies on mission-oriented policies in sustainability transitions in three ways: with empirical findings from the Nordic process industries, insights into policy challenges when shaping transition processes, and guidelines on how systems could be studies to support mission-oriented policy research and practice. First, the cases show that in the Nordic process industries, the combination and sequencing of market mechanisms, innovation and industrial policies mattered for the direction and development of innovation and industrial development, by influencing which actors enter when into new technological fields and how they structure their activities. Second, the cases also reveal challenges for policymakers, for example, in anticipating, monitoring and analysing the interpretations, strategies and behaviours of innovation and industry actors or orchestrating the emergence of multiple value chains. Third, building on the derived analytical framework and lessons from the empirical studies, this thesis proposes some guidelines on how systems could be studied to support the alignment of policy processes and policy mix design in societal missions.

Keywords: industry transformation, sustainability transitions, missions, policy mixes, policy feedback

List of appended papers

This thesis builds on the work of four appended papers:

Paper I: Hedeler, Hellsmark, Söderholm, Sandén.: Shaping domestic industry growth in global sustainability transitions: a comparative analysis of biofuels in Finland and Sweden *(in draft)*.

Paper II: Hedeler, Hellsmark, Söderholm: Policy mixes and policy feedback: Implications for green industrial growth in the Swedish biofuels industry. *Renewable and Sustainable Energy Reviews (2023)*.

Paper III: Hellsmark, Andersson, Hedeler: Leaders and Laggards: The Role of Incumbents in Transformative Policy Missions *(under review)*.

Paper IV: Hedeler and Hellsmark: Cutting across sectors, solutions, and goals in transformative missions: the roles of key actors in the net-zero transitions of the Swedish industries *(in draft)*.

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1 Introduction

1.1 Motivation and Problem Statement

Addressing grand societal challenges has become a key issue on global public policy agendas (Schot and Steinmueller, 2018). Such challenges are typically defined as critical issues that are global in nature, such as climate change, public health crises, food security, energy sustainability, and social inequality (see, for example, Voegtlin et al., 2022). Grand challenges are often complex and interconnected, in brief, "wicked", requiring insights from multiple disciplines to develop innovative solutions. Thus, effective collaboration among stakeholders across various sectors and systems, including government agencies, private sector actors, non-profit organisations, and civil society is essential.

Mission-oriented policies have re-emerged in recent years as a basis for policy action to tackle such cross-sectoral challenges. Scholars have argued that there is much to learn from previous missions for the design and implementation of future-oriented initiatives aimed at addressing pressing societal challenges (Mazzucato, 2018). During the 1960s, missions in the United States were instrumental in enabling and advancing moon landings by establishing clear objectives that addressed specific challenges, fostering a culture of experimentation, and integrating expertise from multiple disciplines (Robinson and Mazzucato, 2019). Analogously, it is argued that societal missions can help foster long-term commitment from policymakers and stakeholders toward clear objectives and navigate the uncertainties inherent in complex challenges (Mazzucato, 2018).

Recent surveys of global policy developments have shown that countries have adopted various ideas on how to implement missions, ranging from targeted national initiatives to broader international collaborations (cf. Larrue et al., 2024). Despite their popularity, however, many missions face challenges in the execution, including issues related to coordination among stakeholders, measurement of outcomes, and the need for adaptive governance structures to respond to changing circumstances. Many argue that these challenges can be traced back to the complexity of innovation systems and the uncertainties and risks inherent to technological change (Bergek et al., 2023; Wanzenböck et al., 2020).

Consequently, the question arises of how policymakers can effectively implement missions to address societal challenges. Mission-oriented policies differ from earlier innovation policies by focusing on transformative change rather than just investing in knowledge infrastructure and R&D, and promoting linkages and learning among key actors across national, sectoral, regional, and transnational innovation systems (Haddad et al., 2022; Schot and Steinmueller, 2018). Missions thus represent a paradigm shift in policy approaches towards a more dynamic and goal-oriented approach. This shift has significant implications for how policy frameworks need to be designed, implemented, and

evaluated. Specifically, it calls for a more integrated, adaptive, and impact-focused approach to governance and innovation (Fagerberg, 2018; Frenken, 2017; Hekkert et al., 2020; Weber and Truffer, 2017).

1.2 Background and State-of-Art

The sustainability transitions literature has a growing interest in transformative and mission-oriented policies to facilitate and promote sustainability transitions (cf. Haddad et al., 2022). Sustainability transitions encompass the processes and dynamics through which production and consumption patterns shift from unsustainable practices to more sustainable configurations, involving the interplay of innovations, established regimes, and broader contextual factors (cf. Markard and Truffer, 2008). Systems transform along pathways shaped by various factors, including technological developments, market dynamics, and institutional influences, which may not always align with long-term societal goals (Geels and Schot, 2007). Consequently, this literature stresses that policy is essential to setting collective priorities and monitoring, evaluating, and shaping the direction of societal missions towards long-term systemic change (Schot and Steinmueller, 2018).

Despite increasing attention to the central role of policymakers in societal missions, there is insufficient understanding of the role of policymaking to effectively support such missions (Haddad et al., 2022; Penna et al., 2024). So far, the debate has remained largely conceptual, with relatively little insight into lessons from empirical studies. Without addressing this gap, however, there is a risk that societal missions will fail to achieve their transformative potential due to poorly aligned or mismanaged policies (Bergek et al., 2023; Steen et al., 2023).

Achieving societal missions, such as climate neutrality or social equity, requires coordinated action and a profound understanding of the mechanisms through which policies drive change. As grand societal challenges are often complex, contested, and multifaceted, policymakers may need to take lead roles in translating societal challenges into clear and manageable objectives that can guide collaborative efforts among various actors (Mazzucato, 2018; Schot and Steinmueller, 2018). However, prior experience shows that the leeway of policymakers in the agenda-setting process and the prioritisation of certain issues over others is often impacted as various actor groups may lobby for specific goals that align with their interests (Avelino et al., 2016).

Adding to this complexity, policymakers need to design a mix of policy instruments (e.g., regulations, funding, incentives, public-private partnerships) that can effectively support transitions (Azar and Sandén, 2011). Well-designed policy mixes can help address the multifaceted nature of societal challenges, ensuring that various aspects of the transition are supported simultaneously, while also allowing for the flexibility to adapt to emerging needs and conditions, thereby enhancing the overall

effectiveness and coherence of the policy framework (Edmondson et al., 2020a; Rosenow et al., 2017). Arguably, this is particularly important for mission-oriented policies in sustainability transitions, where goals are semi-specific, uncertainties and complexities are manifold, and diverse options and pathways may be pursued. Although it has been suggested that tailoring policies to intervention points may shape direction of change in systems (Kanger et al., 2020), existing literature provides limited insight in how and why specific actions can lead to desired changes in directionality to achieve societal missions.

Moreover, existing frameworks often provide little guidance on how policy processes and policy mix design could be better aligned to address mission goals. For example, scholars have proposed frameworks to capture the performance of temporary innovation systems in response to societal missions (Elzinga et al., 2023; Hekkert et al., 2020; Wesseling and Meijerhof, 2023). This includes assessing the roles of various actors, the governance structures in place, and the processes that drive innovation and change (Elzinga et al., 2023). However, these studies provide too little insight into the complexities of policymaking and tend to underplay the impact on the transformation of production and consumption patterns. Given that missions often aim for transformative changes in emission-intensive sectors (e.g., energy, transportation, agriculture), there is a need for an analytical framework that considers the current industry structure and actor strategies as well as future options and pathways that are in line with the mission.

To conclude, an improved understanding of the role of policymaking is needed, as well as actionable frameworks to help policymaking address these challenges. Better knowledge of the dynamics that underpin policymaking is of interest to researchers and may serve as inspiration for policy practitioners.

1.3 Research aim, research questions, and outline of the thesis

The aim of the thesis is to improve understanding of the role that policymaking plays in achieving societal missions. The work in this thesis is guided by two research questions:

First, what can we learn from historical and ongoing transformations about the role of policy?

And second, how can the policy process and policy mix design be improved to better align with societal missions?

To answer these questions, this thesis departs from the innovation systems approach and directs attention to both what a system does and what it consists of. Specifically, it combines two approaches to define the scope and components of a system: a structural perspective, which puts emphasis on the

key actors, technologies, and institutions, with functional thinking, which foregrounds the activities and processes that these elements perform. Linking who is involved with what they do arguably offers a more holistic picture of how the system operates and can guide policymaking in a more comprehensive way.

Empirically, the thesis draws upon empirical evidence from the historical and ongoing transformation of the Nordic process industries. The Nordics serve as an interesting setting for improving knowledge of societal missions since there have been long-standing strategic policy interventions designed to guide industries in aligning their operations and practices with long-term societal goals, resembling the key features of mission-oriented policies in sustainability transitions. The transformation of the incumbent process industry sectors can be considered a complex challenge due to the interplay of entrenched technologies, high capital costs, regulatory constraints, and the need for systemic changes across interconnected supply chains and production processes (Nykamp et al., 2023; Steen et al., 2023). Moreover, there has been a long-standing push from policymakers in the Nordics across these sectors to adopt more sustainable practices, technologies, and processes (e.g., Hansen et al., 2024). Thus, understanding what policymakers could and could not accomplish so far in shaping the transformation of process industries should provide insights into the role of policymaking in societal missions.

The rest of the thesis is organised as follows. Section 2 reviews the innovation systems approach and draws on insights from additional literature, such as studies on policy mixes in sustainability transitions, to outline the analytical framework of the thesis. In Section 3, the empirical setting of the thesis is described, including the rationale for case selection. Section 4 describes the methodological approach of the thesis, including research design, data, and methods. Section 5 summarises the main findings of the thesis. Section 6 discusses the findings of the thesis by deriving lessons from the cases, discussing implications for mission-oriented policies in sustainability transitions, and proposing an actionable framework. Finally, Section 7 concludes the thesis.

2 Theoretical background and points of departure

2.1 Innovation systems and innovation policy

The innovation systems (IS) approach broadly deals with the factors that drive innovation and their implications for economic performance and societal well-being. The IS approach emerged in the 1980s as a response to the need for a more nuanced understanding of innovation processes beyond a linear conceptualisation, primarily driven by research and development (R&D) within firms (cf. Lundvall, 2007). The IS approach emphasises the collective and institutional aspects of the innovation process, suggesting that the development, diffusion, and use of new knowledge and technologies result from the actions and interactions of various private and public actors operating within specific institutional frameworks (Carlsson and Stankiewicz, 1991; Freeman, 1988). In the sustainability transitions field, the technological innovation systems (TIS) approach has gained prominence, focusing on the dynamic and contextual nature of technological innovation systems, and providing insights for researchers and policymakers aiming to foster technological innovations (for a review, see Bergek, 2019).

In recent years, scholars have called for a reframing and renewing of the innovation systems approach to effectively tackle current and future challenges (Frenken, 2017; Hekkert et al., 2020; Weber and Truffer, 2017). In comparison to previous interventions, policies addressing grand societal challenges only have semi-specific goals - not economic growth or development in general, nor the development of a specific solution/technology but something in between related to a societal challenge (such as climate change).

These calls have led to a growing body of literature in the transitions field. Scholars have argued that taking a process-oriented view on mission-oriented policies is important and emphasise alternative pathways to achieve convergence between problems and solutions (Wanzenböck et al. 2020). Others have focused on studying innovation and transition processes resulting from missions, through extending the functional TIS approach to also capture the destruction of incumbent sectors and the coordination of sectors and solutions (Elzinga et al., 2023; Wesseling and Meijerhof, 2023). In addition, scholars have focused on the capturing of the outcomes of innovation and transition processes, by outlining a goal-sector-solution space, which serves as a conceptual tool to categorise and monitor the outcomes of innovation activities (Andersson and Hellsmark, 2024).

However, despite these conceptual developments, there is still a need for broader frameworks that can guide policymaking by providing a more holistic perspective on policy and industry changes (cf. Weber and Truffer, 2017). Following from the focus on semi-specific societal policy goals, this thesis argues that there is a need to understand how systems transform relative to the overarching goals of societal missions, with a particular focus on directionality and the early phases of development.

2.2 Conceptualising systems: structural and functional boundaries

In the innovation systems literature, the delineation of system boundaries is a central theme, with implications for the "who" and "what" of innovation, i.e., the actors, networks, and institutions are considered important. In the foundational national innovation systems (NIS) approach, structural boundaries are set at the national-state level, focusing on how national institutions, policies, and actors influence innovation within a country (Freeman, 1988; Lundvall, 1992; Nelson, 1993). In a similar vein, regional innovation systems (RIS) consider regional governments, local firms, universities and regional developmental agencies as key actors (Asheim and Gertler, 2005), while sectoral innovation systems (SIS) put emphasis on sector-specific actors and institutions (Malerba, 2002). In contrast, the technological innovation systems (TIS) approach introduces a functional boundary around technologies, shifting the focus towards meso-level processes between technology-specific actors, networks and institutions that lead to innovation (e.g., market formation or legitimacy creation) (Bergek et al., 2008b, 2008a).

However, sustainability transition scholars have argued that the IS approach gives too little insight on the transformation of sociotechnical systems (Andersson et al., 2023). They argue that path dependencies can create barriers to change (Geels, 2010, 2002), making it essential to understand both the dynamics of innovation and the constraints imposed by existing systems. The theoretical roots of the sustainability transitions literature encompass a blend of sociology, evolutionary economics, institutional theory, complex systems theory, and transition management (Rip and Kemp, 1998, 1997). The core assumption of the Multi-Level Perspective (MLP) is that transitions towards sustainability or other systemic changes occur through the interaction and alignment of three distinct levels: the niche, the regime, and the landscape (Geels, 2012). The MLP emphasises that the transformation of sociotechnical systems can follow different trajectories, or pathways, during transitions, e.g., reconfiguration or substitution (Geels et al., 2016; Schot and Steinmueller, 2018). The MLP acknowledges the role of agency in driving change but primarily focuses on structural factors and interactions between levels (de Haan and Rotmans, 2018).

Markard and Truffer (2008) have taken a first step into linking the TIS approach and the MLP. The connection is made by examining how evolutionary dynamics (the processes of variation, selection, and retention) and alignment processes (the coordination of interests and resources among actors) operate across different levels of the socio-technical system, facilitating a deeper understanding of how innovations emerge and gain traction. Thus, one system exists in which networks of actors (such as firms, research institutions, and government agencies) interact within a specific institutional framework to generate, diffuse, and utilise technology and innovations. This thesis aims to take this conceptualisation one step further. The review of the innovation systems approaches shows that there

are two ways to delineate the system in focus. First, structural boundaries define the components and relationships that make up the system, encompassing social, technical, and ecological elements. In addition, functional boundaries clarify what activities are included in the analysis of the system.

Together, these boundaries help understand the complexities of systems and guide empirical investigations and theoretical developments. However, a common criticism is that the innovation and transition literature provides too little insight into the configuration of systems (Andersson et al., 2021; Weckowska et al., 2025). Shape refers to the structural features of systems, encompassing the key components such as actors, technologies, and institutions, as well as how these elements are organised (Geels et al., 2016).

2.3 Conceptualising the shape of systems: configurations of value chains

For the purpose of this thesis, this thesis draws on the literature on technology and industry lifecycles (Abernathy and Utterback, 1978; Arthur, 1989; Klepper, 1997; Utterback and Abernathy, 1975). Building on this work, (Sandén and Hillman, 2011) suggested that technology can be defined as a "bundle of value chains," which includes multiple upstream supply chains (the processes and resources needed to produce the technology) and downstream application chains (the ways in which the technology is used). This perspective emphasises that value chains are part of larger systems that may span across multiple sectors and countries (Hipp and Binz, 2020; Van der Loos et al., 2022; Yap and Truffer, 2019), emphasising that domestic firms often collaborate with international partners, including suppliers, customers, and research institutions.

Andersson et al. (2021) have developed a framework to capture the shape of a system. This thesis draws on this framework to describe the shape of systems. First, there is a sociotechnical-sectoral-spatial dimension of configurations, which describes the configuration of value chains. In addition, there is a temporal dimension of configurations, which describes the formation and evolution of value chains over time. Value chains can be linked in different ways, for instance, incumbent steel value chains may be linked to emerging hydrogen value chains. Taken together, configurations help to describe the shape of the system.

2.4 Shaping directionality: policy effects, impacts, and feedback

The importance of strategic policymaking for promoting innovation and creating robust technological systems that can adapt to changing economic conditions and global challenges has been emphasised already in the early 1990s (Carlsson and Stankiewicz, 1991). Metcalfe (1995) combined an evolutionary perspective on technology policy with the national innovation systems framework,

stressing that effective technology policy should focus on understanding and enhancing the innovation process within a broader system of interconnected institutions, rather than merely targeting individual innovations or technologies. In the transitions literature, scholars highlight the importance of recognising the limitations of technology neutrality and advocate for a more pragmatic approach to climate policy that includes both market mechanisms and targeted support for specific technologies to achieve meaningful emissions reductions (Azar and Sandén, 2011; Schmidt and Sewerin, 2019). Others emphasise the governance of transitions, drawing on the notion of a transition arena in which policymakers and stakeholders may come together to develop a shared vision, identify and select solutions, and influence policymaking (Loorbach, 2007). However, a common criticism of the innovation systems approach is that policy process and policy mix are under-conceptualised (Flanagan et al., 2011).

To study the role of policymaking in shaping innovation and transformation processes, this thesis is based onstudies on policy mixes in sustainability transitions. A policy mix defines the strategic approach taken by policymakers to integrate various policy instruments and measures to achieve specific objectives (Rogge and Reichardt, 2016), such as net-zero industries missions. A policy mix is linked to the rate and direction of change in a transitions context through the design, e.g., how consistent different instruments are aligned with overarching goals (Howlett and Rayner, 2013, 2007). Others have stressed that identifying and leveraging intervention points, e.g., stimulating niches or coordinating multi-systems transitions, can help steer systems towards more sustainable outcomes by addressing root causes and critical problems (Kanger et al., 2020).

Other scholars have focused on the role of policy processes in sustainability transitions (Kern and Rogge, 2018). To conceptualise policy processes, scholars often draw from public policy literature on policy feedback theory (Daugbjerg and Kay, 2020; Pierson, 1993). In a transitions context, a policy feedback loop is composed of effects and feedback mechanisms that link policy mixes and sociotechnical change, according to (Edmondson et al., 2020a). Policy effects refer to the immediate consequences of a policy, which can be categorised into resource (e.g., changes in availability and allocation of resources), interpretive (e.g., how policies shape perceptions) and institutional effects (e.g., changes in institutional arrangements and capacities). Feedback links effects to the policy subsystem and policy mix, which can be positive, leading to increased policy support, or negative feedback, limiting leeway for future policymaking processes, e.g., from failures or unintended consequences. Together, these concepts help to describe and explain how policy mixes influence how transition dynamics unfold, both through policy processes and policy mix design (Edmondson et al., 2020b; Gomel and Rogge, 2020; Schmid et al., 2020; Thonig, 2021).

However, scholars have noted that this literature pays too little attention to the impacts of policy mixes, that is broader and long-term changes in socio-technical systems (e.g., changes in emissions,

industry structures or technology adoption) (Kern and Rogge, 2018). While many studies focus on the interplay of policy effects and feedbacks, this literature has not fully entangled how policy effects and feedbacks link to outcomes, i.e., changes in production and consumption patterns.

Therefore, it is helpful to draw from ideas on actors and agency elaborated in innovation systems and transition studies. In the TIS literature, Hellsmark and Jacobsson (2009), for instance, conceptualise actors as equipped with a "transformative capacity," which refers to their ability to intervene in existing systems and influence outcomes, e.g., by creating actor networks, value chains and diffusing new knowledge. Taking it one step further, Markard and Truffer (2008b) view actors with distinct roles, capabilities, and resources, and discuss the concepts of actor configurations and resource profiles to link actor-level analyses to meso-level analysis. Similarly, transition scholars suggest to focus on how actors as agents of change join forces based on shared values, facilitating collaboration and collective action towards systemic change (cf. Bhamidipati, 2019). de Haan and Rotmans (2018) propose a typology of actor roles, categorising them based on their strategies, motivations, and capacities to understand how different actors contribute to transformative change. Similarly, Heiberg et al. (2022) propose a framework to study actors as key participants in socio-technical systems whose interactions, narratives, and coalitions significantly influence innovation dynamics. Arguably, insights from these studies help to link policy effects, i.e., changes in behaviours and strategies of actors, to systems and impacts on production and consumption patterns. However, these studies still pay too little attention to the directionality of change.

To study how the strategies and behaviours of actors align with long-term societal policy goals, this thesis draws on the directionality framework developed in previous literature (Andersson and Hellsmark, 2024). This framework proposes to capture the directionality of innovation through the sector, solution, and goal dimensions. Arguably, this helps to conceptualise the responses of actors, by disentangling their strategies in relation to the policy goals, and their interconnectedness in networks and technologies.

Having outlined the theoretical building blocks and relevant insights, the task is now to combine these into an analytical framework and link it to the conceptualisation of systems developed in sections 2.2 and 2.3. To accomplish this task, this thesis first outlines the key elements of this analytical framework and then turns to the processes and outcomes within this framework.

Specifically, I depart from the system and the conceptualisation of its shape, and add the policy perspective. Policy adds a directionality perspective to changes in the system. Directionality helps to define the structural boundaries considering which sectors, actors and technologies are in focus and also the functional boundaries, i.e., which activities are in focus.

Turning to the processes and outcomes within this directionality framework, Edmondson et al. (2019) have combined many of the insights from the reviewed literature into an analytical framework,

capturing the interplay between policy mixes within policy subsystems and policy effects and feedback mechanisms. These mechanisms illustrate how actors and organisations interact, contributing to the overall direction and development of the system. Following the suggestions by Kern and Rogge (2018), this thesis adds to this conceptualisation to study the long-term impacts of policies by incorporating the system shape.

To achieve this, this thesis departs from the actors in the system. Markard and Truffer (2008b) and Hellsmark and Jacobsson (2009) and de Haan and Rotmans (2018) have combined the links between actors, their roles in systems, and influences on system structures into analytical frameworks. This thesis adds to these conceptualisations of actors in systems by incorporating their responses to policy within the overarching directionality framework. This means that each actor can be studied through a directionality lens, by relating their strategies (i.e., have actors set ambitions or goals to comply with policy) and behaviours (their interactions and contributions to IS dynamics) to policy.

Arguably, this helps to capture changes in the strategies and behaviours actors in response to policies. It also helps to study outcomes of such processes, e.g., changes in interactions and network patterns. Moreover, since the strategies, behaviours and outcomes of actors are interlinked, it also becomes possible to see whether developments of actors are in line with policy ambitions. For example, an actor might plan to invest in commercial biofuel production, while policy goals aim for advanced technologies. In this case, the framework might help to see that the strategies of actors are not aligned with policy goals.

Returning to the overarching framework outlined above and the general interest of the thesis in the role of policymaking in shaping changes in production and consumption patterns. Figure 1 brings the building blocks together and illustrates the interplay of policy effects and feedback mechanisms that facilitate the development of policy mixes, innovation and the transformation of production and consumption sectors. These mechanisms illustrate how actors and policymakers interact, contributing to the overall direction and development of the system.

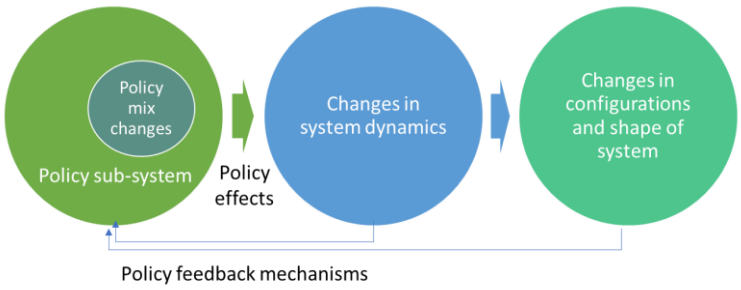

Figure 1: Key building blocks of the analytical framework: policy mixes developed by policy sub-system, system dynamics and configurations and shape of the system (building on Edmondson et al. 2019, Hedeler et al. 2023)

In the early stages of interactions, the focus might be on translating societal challenges into measurable goals, such as emission reductions, changes in production and consumption patterns, or domestic industry growth. Later on, policymakers and other organisations could try to promote new technologies and enhance system-wide innovativeness by providing resource and interpretive effects, even to specific actor types, such as incumbent industry firms.

Not all actors might be actively engaged in addressing coordination and governance in a specific challenge. Therefore, it is useful to draw on the notion of a transition arena (Loorbach, 2007), which helps to capture this specific subset of actors in the system. While the transition arena is focused on coordinating efforts among specific actors working towards a societal transition, transformation can still occur through the actions and influences of actors outside of this arena. Their contributions can, for example, drive innovation and facilitate systemic change that aligns with the long-term societal goals, directly or indirectly.

Policy feedback dynamics refer to the processes through which the outcomes of actions or policies influence future actions or policies (e.g., self-reinforcing or self-undermining). In this thesis, it is assumed that policy feedback dynamics play a significant role in alignment; as policies are implemented and their effects are observed, stakeholders may adjust their strategies and interests to better align with successful outcomes, thereby reinforcing the transition.

Evolutionary dynamics encompass the processes through which systems change and adapt over time. This includes the emergence of new technologies, practices, and policies as well as the adaptation of existing ones in response to internal and external pressures. New technologies or practices may emerge that require realignment of existing policies or stakeholder strategies. This evolution can create new feedback dynamics, as the impacts of these changes are assessed and responded to by various actors within the system.

In this thesis, it is argued that this analytical framework provides a useful lens to study the role of policymaking in shaping sustainability transitions and industry transformation because it allows to follow the process relative to long-term societal goals. In comparison to previous systems approaches, it helps to develop a holistic understanding of how policy influences which types of actors enter transitions, and which activities they pursue. In the following sections, this thesis draws on this framework to study the role of policy in shaping the direction, development and outcomes of industry growth and transformation in the Nordic process industries.

3 Empirical setting

3.1 Transformation of the Nordic process industries

The empirical setting of this thesis is the transformation of the process industries towards net-zero emissions. Accelerating the transition of incumbent industries towards net-zero emissions is fundamental to meeting stringent climate policy goals until mid-century. To date, the industry sectors are one of the largest emitters worldwide, accounting for 9.0 Gt of CO_2 in 2022 (around 25% of global energy system CO_2 emissions) (IEA, 2024). Despite some progress, however, the transition is off track to meet the 2050 climate policy goals of net zero emissions. Recent estimates of the International Energy Agency show that new policy frameworks are needed to meet the 2050 goals and for emissions to drop by 2.0 Gt CO_2 to reach global interim targets in 2030 (IEA, 2024). At the same time, geopolitics and risks of supply chain disruptions increasingly force policymakers to prioritise strategic autonomy (Edler, 2020; Edler et al., 2023). Indeed, many countries and international organisations, such as the US, China, India and the EU, have started to integrate technology sovereignty considerations into green industrial policies (Caravella et al., 2021; Criscuolo et al., 2022).

A range of solutions, such as the adoption of low-carbon technologies, process optimisation, and improved energy efficiency, exist that can be used to transform industries and contribute to low-carbon production processes. Different industries have unique processes and emissions profiles but also share common characteristics. In general, emissions in process industries come from a combination of fossil fuel combustion, process emissions, chemical reactions, energy use, transportation, waste management, material choices, refrigerants, and operational inefficiencies. A single technology may not be sufficient to address all sources of emissions within an industry; on the contrary, eliminating these emissions typically requires a multifaceted approach (Davis et al., 2018). For example, the steel and cement industries have specific challenges that require a combination of electrification, hydrogen, carbon capture and storage (CCS), and alternative materials to effectively reduce emissions (Bataille et al., 2018). While some low-carbon options like solar and wind energy are mature and widely deployed, others, such as CCS, advanced biofuels, and green hydrogen, are still in earlier stages of development (Davis et al., 2018).

This thesis focuses on the transformation of the Nordic process industries. Process industries refer to sectors such as the forest industry, chemicals, and steel, which convert materials (Lager et al., 2013). The resulting products are also often materials, for example, concrete, which can be used for cement production (Karttunen et al., 2021).

Building up and maintaining key parts of low-carbon value chains, however, is a complex challenge. Firms in incumbent process industries operate in global markets with intense competition. Concerns

about maintaining competitiveness, especially in regions with less stringent environmental regulations, can deter investments in decarbonisation efforts that may increase production costs. Moreover, incumbent process industries often have complex value chains with interconnected processes and dependencies (Bauer et al., 2022). Decarbonising one part of the value chain may have implications for other parts, requiring a holistic approach to decarbonisation that considers the entire sector (Nilsson et al., 2021).

On a general level, the process industry sectors in the Nordics can be characterised by relatively small but highly internationalised industry structures. Few firms and complementary actors exist in each sector, with emissions closely linked to few actors (Hansen et al., 2024). Despite the relatively small sector size, the potential impact of world markets on the Swedish process industries is of importance. In fact, in Sweden, for example, the production of chemical products, steel, and mining is supplied to 80 per cent to global markets; only cement is mainly produced for the home market (Karltorp et al., 2019). It is worth noting that this is still very little from a global perspective. The Nordics are interesting because of their long-standing and strong commitment to sustainability and environmental issues in the process industry (Calmfors et al., 2019). For example, Sweden implemented already in the 1970s several policies, for example, to transform the pulp and paper industries (Söderholm et al., 2017) and promote gasification and biofuel technologies (Hellsmark, 2010; Hillman, 2008). Sweden and Finland have been the first countries to implement a CO_2 tax in 1990/1991 (industry exempted) (Åkerfeldt and Waluszewski, 2018). Moreover, since the Paris Agreement in 2016, the Nordic countries have policies to accelerate industry transformation towards net-zero emissions (Hansen et al., 2024; Nilsson et al., 2021), such as public R&D funds (Sweco, 2023). Thus, it is arguably a suitable setting to capture both historical dynamics and the prospective transformation towards net-zero across multiple sectors.

This thesis draws on three cases: the historical and ongoing development of biofuels in Finland and Sweden over an extended period (2003-2020) and the Swedish net-zero transition of the process industries (2017-2022).

The initial focus of the thesis has been on biofuel cases. During the time of case selection, biofuels were one of the few technologies in the Nordics that are relevant for the fulfilment of climate policy goals, that have implemented policies, and that have achieved sufficient progression to be able to provide insights for the research aim of the thesis. This case selection has been informed by previous knowledge of the cases (Hellsmark et al., 2016; Hellsmark and Söderholm, 2017; Hillman et al., 2008). The selection has also been influenced by previous studies on specific biofuel technologies in the countries, such as gasification (Hellsmark 2010) and bioethanol (Ulmanen 2013).

With the rise of net-zero emission goals, the need for studying the transformation of incumbent industry sectors has become more central in the policy discourse. For a country to achieve net-zero

emissions, it matters not only that low-carbon technologies, such as biofuels, are developed, but also if and how incumbents transform and maintain large parts of value chains in the country. This has motivated to broaden the focus from focusing on technologies (with an emphasis on the functional boundaries) to also put stronger emphasis on the incumbent industry sectors (combining structural and functional boundaries). The case selection has also been informed by prior knowledge of the sectors (Andersson and Hellsmark, 2024; Bergek et al., 2023; Karltorp et al., 2019).

Overall, the cases thus help to address the relationship between policies and the direction, development, and outcomes of industrial development and transformation from multiple angles. While policies in all cases focus on similar system elements, that is multiple sectors, actors and technologies, the focus of the policies has been set differently, ranging from specific biofuel policies in the first two cases to a challenge-oriented approach in the third case. Understanding the impacts of the policies on the development and direction of industry development is interesting in itself. In addition, it is argued that this comparison can also provide lessons for mission-oriented policymaking.

3.2 Research cases

Case 1 and 2: Biofuel technologies in Finland and Sweden

This thesis draws on an in-depth analysis of biofuels. Biofuels can be defined as renewable energy sources derived from organic materials, i.e., biomass, which includes plant and animal matter (Davis et al., 2018). Biomass can be converted into liquid biofuels or gas through different production processes, such as fermentation (for ethanol), transesterification (for biodiesel), and gasification (for synthetic fuels). The resulting biofuels can be used in various applications, including transportation (as gasoline or diesel substitutes), heating (in residential and industrial settings), and electricity generation (in power plants). These compounds can also be used as feedstock in the production of other chemicals. Biofuels have been in use for many years, with established production processes for certain types (e.g., ethanol and biodiesel). In contrast, advanced biofuels are still developing and are not as widely adopted (Oh et al., 2018).

In many countries, policymakers have undertaken substantial efforts during the past decades to support the adoption of biofuels and localise large shares of new global value chains in home countries (Giuntoli, 2018; IEA, 2021). The Nordics make a particularly interesting case since they have become a global frontrunner in the biofuels field (ETIP Bioenergy, 2020). The long development history and industrialisation outcomes thus enable theoretical insight into the key mechanisms underpinning changes in the shape of sociotechnical systems and the role of policies in shaping the direction of systemic change.

We selected Finland and Sweden as cases for two reasons. First, both countries developed biofuel policy mixes and experienced industrial growth during this period (Hellsmark and Söderholm, 2017; Ministry of Economic Affairs and Employment, 2017). Second, both countries had similar conditions for the emergence of biofuel industries from the outset, such as rich forest resources, similar technology capabilities and industry structures, and environmental legislation (Hellsmark, 2010). For this reason, they also had fairly comparable prospects for inducing novel industrial growth paths. Nevertheless, they have developed partly contrasting industry structures, which provide a starting point to elaborate the role of the respective policy mixes.

This thesis argues that biofuels also allow us to derive more generic lessons and insights for other low-carbon technologies, such as carbon capture or hydrogen. For instance, biofuels share similarities with many other low-carbon technologies in terms of technology architecture, integration into existing systems, and sociopolitical factors. The architecture of biofuel technologies often allows integration into existing industrial sites, such as oil refineries or pulp mills, with moderate infrastructure changes (Lönnqvist et al., 2021). This is similar to other low-carbon technologies that can complement or retrofit existing systems, like energy efficiency measures or carbon capture and storage (CCS). In terms of sociopolitical factors, the development of biofuels has been heavily driven by public policy, similar to the current uptake of other low-carbon technologies to achieve net-zero emissions in industry.

Case 3: Swedish net-zero industries transition

The second empirical focus of this thesis is on the Swedish net-zero transitions of the process industries. The transformation in the Swedish process industries is largely driven by the 2017 Swedish climate policy framework to achieve net-zero emissions in 2045 and negative emissions after that. The Swedish net-zero goal has been limited to territorial emissions from activities in Sweden (Ministry of Climate and Enterprise, 2021), with implications for transforming established value chains in the process industry sectors. The limitation to territorial Swedish emissions implies that the focus in the established production-consumption systems of the process industry sectors is on emissions resulting from the producing rather than using sectors, i.e., through imported products (Bergek et al., 2023). Moreover, the accounting method only includes direct emissions from industrial processes (e.g., production of basic materials), leaving out emissions from raw material extraction (e.g., mining sector) (Bergek et al., 2023). As a result, the primary focus in the Swedish process industry is on decarbonising the producing sectors through technological innovations and carbon capture. To support the transition of the incumbents across the Swedish industries towards net-zero emissions, the government implemented a collaborative R&D programme Green Industry Leap ("Industriklivet") in 2017 (Sweco, 2023). The cross-sectoral target group of the policy instrument

enables to capture both the impact of policies and how innovation dynamics unfold across multiple sectors and solutions. In addition, technology-specific policies, for example, to support the adoption of biofuels and the development of different technologies (e.g., gasification, fermentation), have been in place in Sweden for many decades (Hellsmark, 2010; Ulmanen, 2013). Thus, due to the implemented policies, this case is suited for the purpose of this thesis.

In this case, two research settings have been selected. The first setting departs from the process industry sectors and focuses on the responses of incumbent actors to missions, focusing on their strategies and behaviours within the system. This encompasses an analysis of their activities within the collaborative R&D programme Green Industry Leap, as well as their wider activities.

The second setting narrows down the focus to the activities within the R&D programme Green Industry Leap. This setting involves all stakeholders and actors involved in the network, such as research institutions, incumbent industry firms or new entrants. This allows for a deeper dive into the mechanisms and processes at play within that initiative, and helps to provide diverse perspectives on the responses of actors to missions, their interpretations, and key challenges. This reveals challenges, opportunities, and innovations that may not be apparent when looking at incumbents alone.

4 Methodology

4.1 Research Design

The thesis applies qualitative research strategies to answer the research questions through case analysis. Qualitative strategies are particularly useful when exploring new or poorly understood topics, where existing literature is limited or where current theories do not adequately explain observed phenomena (Eisenhardt, 1989).

Systems can be analysed at different levels, e.g., actor-oriented (Markard and Truffer, 2008b) or at the meso-level (Bergek et al., 2008a), and with different emphasis, focusing on the configurational (Heiberg et al., 2022) or functional evolution of systems (Bergek et al., 2008b). This thesis maps the system by following the co-evolution of policy, actors, and technologies to uncover system dynamics and policy feedback loops within wider systems (Edmondson et al., 2020a).

4.2 Analytical focus and links to appended papers

Embedded in the analytical framework presented in Section 2, this thesis presents four case studies, each addressing different links and aspects of the framework. All papers contribute to both research questions asked in the thesis.

Paper 1 investigates the role of mission-oriented industrial innovation policies in shaping processes of innovation and industrial development. Specifically, it seeks to explore how the co-evolution of policy effects and feedback shapes the structural development of domestic industries. The paper takes its starting point in the innovation systems approach and draws upon insights from policy feedback theory to capture how the interplay of policy mixes, effects, and feedback shapes domestic industry growth. Empirically, the paper builds on a comparison of biofuels in Finland and Sweden. The paper is linked to the analytical framework outlined in Section 2 by focusing on the relationship between policy mixes and industry shape. The paper contributes to research question 1 with evidence on the role of policymaking in shaping industrial development relative to long-term societal policy goals. It shows how policy shapes which types of actors enter, which activities they pursue, and the resulting structural evolution of domestic industries. By analysing biofuel policies in Finland and Sweden, the paper contributes lessons of how past and ongoing policies influence industry dynamics relative to societal goals like sustainability transitions. To the research question 2, the paper contributes with insights into the delineation of functional boundaries and provides insights into the conceptualisation of shape in a domestic industry setting, and links the shape to the design and implementation of policies.

Paper 2 provides insights into policy feedback loops emerging in the development of domestic industries by studying the case of biofuels in Sweden over an extended period (2003 to 2020). The paper takes its starting point in the debate about directionality of innovation and investigates how the interplay between policies, technologies, and industrial structures influences the direction and subsequent shape of domestic industries in global sustainability transitions. The paper is linked to the analytical framework by focusing on the policy feedback dynamics within systems and the resulting structural evolution of domestic industries. The paper contributes to research question 1 in the thesis by revealing insights into how interactions between policies, technologies, and industrial structures influence the direction and development of domestic industries. By analysing biofuels over two decades, it sheds light on how policy shapes industry trajectories and provides lessons on achieving long-term societal goals through missions. To research question 2, the paper contributes with insights into the delineation of functional boundaries, the analysis of policy feedback loops and subsequent changes in the industry shape.

Paper 3 analyses the responses on incumbents to mission-oriented policies in the Swedish case. The paper departs from the literature about incumbents in sustainability transitions and derives key analytical dimensions capturing the motivation and behaviour of incumbents in the context of net-zero industries missions. The paper is linked to the analytical framework by studying the responses of incumbent industry firms to long-term societal policy goals and mixes. The paper contributes to research question 1 in the thesis by revealing insights on the motivations and behaviours of incumbents in response to policies, highlighting their influence on transitions. It provides insight into how mission-oriented policies challenge or transform incumbent structures in pursuit of sustainability. To research question 2, the paper adds insights into how the responses of actors can be studied in a directionality framework.

Paper 4 studies the dynamics within the innovation networks by focusing on the responses of system entanglers as key actors within systems who aim to link sectoral and technological systems to address mission goals. System entanglers are actors that span multiple sectors and technologies (Kanger et al., 2021; Löhr and Chlebna, 2023) and thus can potentially play important roles in driving progress in missions. The paper draws upon the concept of a system entangler and combines the actor lens with a directionality framework to delineate key analytical dimensions to study system entanglers in the case of Sweden. The paper contributes to research question 1 with insights into how these cross-sectoral actors drive progress by linking technologies and sectors to address mission goals, offering insights into their contributions to multi-system transformations. To question 2, the paper adds insights into how the roles of actors can be studied within a directionality framework.

Together, these papers contribute to the thesis by providing a comprehensive view of how policies influence industrial transitions at various levels: from shaping industries (Paper 1), incorporating

feedback loops (Paper 2), understanding incumbent responses (Paper 3), to leveraging cross-sectoral actors like system entanglers (Paper 4). They collectively improve understanding of how policy processes and mixes can be designed and refined to better align with societal missions, drawing evidence from both historical and ongoing transformations.

4.3 Cases, Data, and Methods

For the empirical analysis, each paper combines multiple data sources and methods to interweave qualitative insights with quantitative data, leading to a more comprehensive understanding of the research questions (Eisenhardt, 1989; Eisenhardt and Graebner, 2007). Papers 1 and 2 use qualitative analysis strategies, while Papers 3 and 4 incorporate social network analysis techniques to complement qualitative methods with descriptive analysis of network structures.

Table 1: Overview of the cases, data, and methods in the appended papers

Research Design	**Paper 1**	**Paper 2**	**Paper 3**	**Paper4**
Purpose	Relationship between policy mixes and impacts on industry structures	Co-evolution of policy mixes, technological and industrial structures	Responses of incumbents to missions	Roles and types of key actors in missions
Key concepts	Policy mixes and shape	Policy mixes, policy effects and feedback, impacts on industry structure	Innovation strategies, resources, interactions	Actors, directionality
Case study	Comparative case study (2003-2020)	Comparative case study (2003-2020)	Snapshot based on time frame 2017-2022	Snapshot based on time frame 2017-2022
Perspective	Historical	Historical	Combines historical perspective with prospective aim of reaching net-zero emissions by 2045	Combines historical perspective with prospective aim of reaching net-zero emissions by 2045
Empirical setting	Biofuels in Finland and Sweden	Biofuels in Finland and Sweden	Process industries in Sweden	Process industries in Sweden
System in focus	Biofuel system, national	Biofuel system, national	Sectoral systems, national	Cross-sectoral network in net-zero industries system, national
Level of analysis	Domestic industry broken down into firm-level value chains	Domestic industry broken down into firm-level value chains	Behaviours and strategies of incumbent industry firms	Actors cutting across multiple sectors and solutions
Data	Semi-structured interviews, secondary data, workshop	Semi-structured interviews, secondary data, workshop	Collaborative R&D programme, secondary data, data on emissions	Collaborative R&D programme, secondary data, semi-structured interviews
Methods	Comparative case study analysis, qualitative analysis	Comparative case study analysis, qualitative analysis	Social network analysis, qualitative analysis	Social network analysis, qualitative analysis
Contributions	Framework, intervention points	Framework, intervention points	Analytical framework to capture responses of incumbents	Framework of cross-cutting actors

Paper 1 builds on a comparative case study analysis of the historical development of biofuels in Finland and Sweden over an extended period (2003 to 2020) to investigate how policymakers have influenced the shape of the respective biofuel industries. Both countries are interesting because they have developed partly contrasting biofuel industry structures, despite similar preconditions and policy ambitions. To analyse the historical development of the biofuel system in both countries, with a particular focus on the links between shape and policy mix, the paper combines data secondary data and 23 semi-structured interviews. The interviews have been conducted with representatives from policy, industry, and the research and consulting sector. The analysis process was highly iterative, involving constant comparison between data and emerging patterns. To verify the preliminary conclusions and refine findings, a workshop with representatives from policy, research, and industry was conducted additionally.

Paper 2 investigates policy adjustments in the context of domestic industry growth. The data for the paper were collected from multiple sources, including semi-structured interviews, secondary data, and newspaper articles. The interviews were transcribed and together with the other data sources, coded in NVivo. The paper uses an abductive approach. We iterated between the concepts of policy feedback, technologies and industry structures from the literature and patterns and codes emergent from the empirical data. For instance, discourses around the legitimation of technologies emerged from the content analysis of newspaper articles. The process model, which explains the interplay of policy, technologies, and industry structures, emerged through this iterative process.

Paper 3 explores the responses of key incumbent firms in Sweden to the national mission of net-zero emissions by 2045. To identify incumbents in Sweden, the paper identifies main emitters through the emission data studies and their responses to net-zero emission goals. Specifically, to identify actors with the highest emissions, the paper draws upon publicly level emissions data on production plants. This approach allowed us to identify the 20 main emitting firms in Sweden. To analyse the responses of the incumbents to the implemented policies in Sweden, the paper combines multiple data sources. Specifically, the capture the motivation and strategies of the incumbents in the net-zero transition, the paper draws on secondary data, such as company reports and industry journals. To measure the engagement levels of the incumbents, the paper uses data on publicly funded RD&D. Specifically, we analysed the financial investments of incumbents in the programme, and studied the collaboration patterns. Together, this allowed us to corroborate qualitative insights with quantitative data, leading to a more comprehensive understanding of the responses of incumbents. For example, it allows us to capture mismatches between high ambition levels and low financial investments or collaboration patterns.

Paper 4 seeks to analyse roles of system entanglers in mission-oriented innovation systems and policy. The paper focuses on the case of the Swedish net-zero transition as an example of a transformation process driven by strong policy ambitions, thus providing insights into the responses of incumbents to missions. By analysing the socio-technical configuration of the Swedish innovation network, we identified central actors who hold system entangling positions within the system. To achieve this task, the paper used a bipartite network analysis approach, meaning that research projects were coded and analysed using both actors and technologies as key constructs. Having identified the actors, we grouped them into three categories, based on the ways through which actors cut across the problem-solution space. For example, actors may come from the problem side and link to multiple solutions to drive innovation activities in the mission. To explore the responses of the system entanglers using the analytical dimensions derived in the paper, we combined secondary data with eight semi-structured interviews.

To answer the research questions asked in the end of section 1, this thesis combined within-in and cross-case analysis. Prior research suggests that this combination helps to familiarise with both cases in-depth, and should provide the foundation for thorough comparison and theory-building (Eisenhardt and Eisenhardt, 2016; Langley, 1999).

While the papers have provided in-depth analyses of the cases, including a comparison of biofuel developments between the Finnish and Swedish cases, this thesis has compared the identified patterns to identify themes across cases. For example, this analysis has focused on the types of actors in the cases, their behaviours and strategies in response to policies. The identified themes were then related to the analytical framework outlined in section 2.

5 Empirical findings

5.1 Paper 1

The paper addresses the shaping of domestic industry growth in global sustainability transitions. In light of supply chain disruptions and geopolitics, there has been growing debate about technology sovereignty as framing for climate policy ambitions (Edler et al., 2023). Policymakers have started to become aware of mission-oriented policies to promote the localisation of strategic value chain segments and help achieve technology sovereignty (Crespi et al., 2021).

The paper investigates the role of policy mix design and implementation in shaping the direction and dynamics of domestic industry growth towards mission goals. Building on the historical development of biofuels over an extended period (2003 to 2020), the paper conceptualises the shapes of biofuel industries in Finland and Sweden as a bundle of domestic value chain segments.

A comparison of the two cases indicates that the interplay between various policy instruments significantly influences the structure and dynamics of domestic value chain bundles. Finland's policies favoured large-scale incumbent firms for biofuel production, while Sweden's approach resulted in a more fragmented industry landscape, promoting primarily technological innovation and distribution of imported biofuels. The paper emphasises the need for a strategic and long-term perspective in policy design, addressing challenges related to market failures and the complexities of interconnected systems.

More broadly, the research underscores the necessity of well-coordinated mission-oriented industrial innovation policies to effectively foster innovation, enhance technological sovereignty, and align national climate transitions with global sustainability objectives. Based on the case comparison, the paper lists five challenges for policymakers in shaping the direction and development of domestic industry growth, relating to the interpretations of policymakers and the responses of industry actors, the formation of value chains, exogenous factors, and policy design.

The paper contributes to an improved understanding of the role of policymakers in shaping domestic industry growth and aligning development with long-term societal goals. It also adds to the IS model by conceptualising industry shapes by differentiating between types of domestic value chains and their related actors.

5.2 Paper 2

Paper 2 draws upon the historical development of biofuels in Sweden to identify key challenges for policymakers in adjusting policy mixes. Despite the key role of effective policies for domestic industry growth, little research has been done on the opportunities and challenges for policymakers to adjust policies over time. This gap is surprising, given that transitions often face political countertrends that can hinder progress (Geels et al., 2016; Jacobsson and Lauber, 2006).

The purpose of the paper is to improve understanding of the implications of policy feedback for the direction and dynamics of domestic industry growth. The paper builds on a longitudinal analysis of the historical development of biofuels in Sweden (2003 to 2020) to examine the interplay of policy mixes and feedback mechanisms for domestic industry growth. During the studied period, the Swedish biofuel policy mix has included various instruments such as taxation strategies, customs tariffs, and blending quotas. These instruments have been designed to support both the use of biofuels and the development of domestic production capabilities. In addition, significant public funding has been allocated to research and development (R&D) activities, particularly for second-generation biofuels. This investment reflects a strong political commitment to advancing biofuel technologies.

The paper shows how the ability of national policymakers to shape industry developments diminished as the industry matured. In the early stages of an industry, such as the biofuels sector, national policymakers often have significant influence over its development. They can create favourable conditions through targeted policies, subsidies, and regulations encouraging investment, innovation, and market entry. This initial support can help nascent technologies gain traction and establish a foothold in the market. As the biofuel industry matures, it typically becomes more self-sustaining. A mature industry often involves complex interdependencies among various stakeholders, including producers, consumers, and regulatory bodies. These relationships can create a situation where industry actors have their own interests and agendas that may not align with government objectives.

The paper identifies several challenges for adapting policy mixes in a green industry context, by (i) revealing diverse policy feedback, (ii) path dependencies, (iii) co-evolutionary dynamics between value chains, (iv) influence of exogenous factors, such as global policy and market developments, and (v) uncertainties and challenges related to innovation processes.

Overall, the paper makes several contributions to the literature. First, by analysing the case of biofuels in Sweden over an extended period, the paper improves understanding of the implications of policy mixes and policy feedback on green industry growth. Second, the paper has implications for policy. Our findings suggest that as the industry matures, policymakers may need to adopt a more adaptive approach, focusing on creating a flexible policy environment that can respond to industry changes rather than trying to control every aspect of its development. This may involve engaging with industry

stakeholders to understand their needs and challenges, allowing for a more collaborative approach to policymaking.

5.3 Paper 3

Paper 3 focuses on the responses of incumbents in the process industries to the Swedish net-zero transformation. Incumbent firms, particularly in industries such as energy, manufacturing, and transportation, are often responsible for a large share of greenhouse gas emissions (Berggren et al., 2015; van Mossel et al., 2018). Their actions directly impact national and global emissions levels, making their engagement in net-zero strategies critical for achieving climate goals. However, there is a lack of empirical research specifically focusing on the role of incumbent industrial actors in transformative policy missions. While there is existing literature on the behaviour of incumbents during transitions (Köhler et al., 2019), findings are often inconclusive and do not provide a clear understanding of how these actors engage with mission-oriented policies. Yet, incumbents often hold significant market power and resources, which can shape the direction and pace of sustainability transitions (Hellsmark and Hansen, 2020). Their strategic actions can either facilitate or hinder progress towards climate goals, making it essential to analyse their behaviour.

The paper aims to fill this gap by providing empirical insights into the ongoing climate transition in Sweden, particularly examining how major emitters respond to national climate goals and the 'Industry Leap' program, which is the main national R&D programme. By focusing on the engagement, collaboration, and strategies of these incumbents, the research seeks to enhance the understanding of their roles and the dynamics involved in achieving climate objectives.

The analysis of the Swedish process industries shows that 20 firms from different segments in the process industry value chain are responsible for nearly 28% of total Swedish emissions. Most firms are working with the production of basic materials, followed by firms in the energy sector. Additionally, some firms work on waste and raw material extraction.

The analysis shows that the main emitters in Sweden have ambitious yet varied climate goals. This indicates that while many firms are committed to reducing emissions, their specific targets and timelines differ significantly. We also observe different levels of engagement among incumbents in terms of attention and investments directed towards decarbonisation efforts. Some firms are more proactive and allocate substantial resources, while others show less commitment. We found that incumbents collaborate to varying degrees with other actors in decarbonisation projects. This suggests that while some firms actively seek partnerships and engage in collaborative initiatives, others may operate more independently or be less involved in cooperative efforts. We also found that incumbents

employ a range of mitigation strategies, reflecting their unique circumstances, capabilities, and market positions.

The paper makes several contributions to the literature. First, by investigating the responses of incumbents to the goals of the Swedish mission, the paper provides novel empirical evidence. Specifically, the paper shows that national missions matter for incumbent industry sectors to transform production processes and achieve deep emission cuts, as incumbents often rely on resources and collaborations. Second, the paper contributes an analytical framework that can be used to measure the responses of incumbents to missions, by focusing on motivations and abilities. And third, the paper provides lessons for the implementation of net-zero industries missions, by highlighting the importance of monitoring the alignment of incumbents with policy ambitions.

5.4 Paper 4

This paper investigates the responses of system entanglers as key actors in driving progress across multiple sectors and solutions in mission arenas. Cross-sector collaboration can speed up the development and diffusion of new low-carbon technologies, such as hydrogen and carbon capture (Andersen, 2023; Andersen and Geels, 2023). To this end, policymakers recognise the importance of implementing mission-oriented R&D programmes to bring actors across multiple solutions and sectors together and promote cross-sectoral innovations.

The purpose of the paper is to develop a framework that can be used to analyse the roles of system entanglers in mission-oriented innovation systems and policy. The paper builds on a case study of the "Green Industry Leap" (Industriklivet) program in Sweden, which serves as a practical example of mission-driven network formation and innovation processes. The paper employs social network analysis to identify and map the actors that cut across different sectoral systems and solutions. In addition to this quantitative analysis, the research combines secondary data analysis with semi-structured interviews. This qualitative approach provides insights into the contributions and challenges faced by different cross-cutting actors.

Building on the empirical case, the paper develops an analytical framework that helps to capture the responses of system entanglers within systems. The research identifies three distinct types of cross-cutting actors involved in the Swedish net-zero industries transition. These actors play complementary roles in linking different sectors and solutions. Each type of cross-cutting actor has unique strategies, networks, and intended contributions to transformative missions. Overall, these actors play complementary roles in linking different sectors and solutions within mission-oriented innovation systems. Some enter the system from the problem side, while others aim to scale solutions. In addition, we also find supporting actors, helping to link sectors and solutions.

Building upon the conceptualisation of cross-cutting actors, the paper proposes a framework that policymakers can use to monitor the emergence and roles of cross-cutting actors in mission-oriented R&D programs. This framework aims to facilitate the integration of multiple sectors and solutions, providing a structured approach to evaluating progress. In the Swedish case, we found substantial gaps and mismatches in the current innovation landscape. For example, there are observed mismatches between the distribution of resources in the Swedish RD&D programme and the roles played by different system entanglers. For instance, if investments are disproportionately directed towards incremental solutions, this may detract from necessary funding for more transformative innovations, creating a zero-sum dynamic that hampers the progress of the Swedish mission. We also found gaps in infrastructure developments and a relative absence of established coordination mechanisms among actors in the innovation landscape. This lack of coordination can result in fragmented approaches and missed opportunities for synergy and learning across different process industry sectors and low-carbon solutions. Together, these gaps can hinder the effectiveness of the Swedish mission-oriented R&D program and the overall progress towards net-zero emissions.

Doing so, the paper makes several contributions to the literature. First, it provides a systematic overview of the roles and activities of system entanglers in missions. Second, it also contributes to the debate about fostering cross-cutting innovations through mission-oriented policies by proposing a strategy that enables policymakers to track progress. Third, the paper also offers lessons from the Swedish net-zero industries transition for policymakers and practitioners who wish to support missions to transform incumbent industries.

6 Discussion

6.1 Lessons from the empirical cases

The case studies have illustrated how policy has influenced the direction and development of innovation and industrial transformation. This section discusses lessons by comparing key patterns across the cases.

The cases suggest that a strategic approach to policymaking is important. Across the three cases, shaping the transformation of incumbent industries towards long-term societal goals required a combination of market mechanisms, innovation, and industrial policies. In the Finnish biofuels case, policymakers combined blending quotas with tax reductions to incentivise biofuels, while supporting the development and production through tailored learning networks, R&D, and investment subsidies. In the Swedish biofuel case, policymakers combined tax exemptions with R&D funds and pilot and demonstration programmes. In the case of the Swedish net-zero transition, the focus has been on the cross-sectoral, collaborative R&D programme, while additional technology- and sector-specific policies exist, such as biofuels. These findings extend the focus from previous research on the interplay between market mechanisms and innovation policies (e.g., Azar and Sandén, 2005) to also include industrial policies.

Unsurprisingly, the cases show that the combination of these policies comes with additional policy challenges. In line with previous research (e.g., Azar and Sandén, 2005), the cases demonstrate trade-offs between long-term objectives and short-term goals, e.g., between different generations of biofuels. In addition, the cases also reveal additional trade-offs between R&D and industrial capacity as policymakers often need to balance investment in innovative research with improving industrial capacity by investing in existing technologies and production processes to increase sustainability and efficiency. Policymakers in the Finnish biofuels case, for instance, emphasised building industrial capacity and supporting established firms, which limited the focus on R&D but allowed for scaling of biofuel production. In contrast, the development of the Swedish biofuels case leaned towards prioritising R&D and technological innovation, which slowed down industrial capacity growth and created a fragmented industry landscape.

The cases indicate that the combination of multiple policies requires careful coordination to ensure they complement each other and can effectively shape innovation and industrial transformation. The cases suggest that policymakers who recognise the importance of combining policies to leverage policy feedback loops can guide innovation and industrial efforts. In the Finnish case, early policies supporting the entry of industrial actors into biofuels, such as Neste Oil, St1 and UPM, led to a self-reinforcing cycle, adjusting industrial policies with innovation and market mechanisms in alignment

with the biofuel developments and resulting in the production and distribution of semi-advanced biofuels. In contrast, the policies in Sweden were more fragmented from the outset, policymakers implemented tax exemptions and R&D subsidies, leading to separate feedback loops, and entrenching the Swedish biofuel development primarily to innovation and distribution. In addition to this fragmentation, the taxation strategy as well as other policies created a lot of instabilities. It was only when problems with the policy mix were addressed that policymakers could initiate positive feedback loops centred on production. These findings tie in with prior research (e.g., Howlett and Rayner, 2013), emphasising the importance of policy packaging, in particular in sustainability transitions (e.g., Rogge and Reichardt, 2016).

The cases also indicate that the sequencing of policies matters. In the Finnish biofuel case, for example, initial policies promoted the development of semi-advanced biofuels (e.g., based on vegetable oils) which at that time could be scaled-up and commercialised relative quickly and allowed for large profits, generating support and buy-in from domestic incumbent industry firms, such as Neste Oil, UPM and St1. This, in turn, made it easier for the government to implement subsequent, more aggressive initiatives focused on higher sustainability, forcing these firms to resume R&D and identify new options. These findings tie in with prior research, suggesting that the design and sequencing of policies could help build momentum for change (e.g., Kanger et al., 2020). The thesis adds to this by providing insights into the mechanisms underpinning the influence on innovation and industrial development, using the cases of the Nordic process industries.

However, the cases also indicate that the process of shaping and guiding the direction and development of innovation and industrial transformation becomes increasingly complex as industries mature. Across all cases, policymakers had to navigate the interactions between various policy instruments, sectors, and levels of governance to effectively influence industry trajectories. As industries mature, the number of actors involved typically increases, leading to a more fragmented landscape where aligning goals and strategies becomes more challenging. In addition, the maturation of industries often involves the emergence of new technologies and innovations, which can disrupt existing market structures and value chains, as illustrated by the growth of imported biofuels in Sweden, hindering domestic production. External influences, such as global market trends, geopolitical developments, and international regulations, can also significantly impact domestic industries, drawing from the cases in Finland and Sweden. As industries mature, policies and actors often become more integrated into global systems, making them susceptible to these exogenous factors. These findings suggest that policymakers must adopt a strategic and adaptive approach to navigate these complexities and effectively guide the development of mature industries towards desired outcomes, such as technology sovereignty and sustainability, supporting prior findings in the literature (e.g., Mazzucato 2018, Schot and Steinmüller, 2018).

6.2 Implications for mission-oriented policies in sustainability transitions

This section returns to the first research question of the thesis, asking what can we learn about the role of policy from historical and ongoing industry transformations?

The thesis complements existing research on missions in sustainability transitions (Haddad et al., 2022; Penna et al., 2024) with lessons on policymaking from the Nordic industry transformation. This thesis builds on the key characteristics of mission-oriented policies and proposes that the policies observed in the historical and ongoing transformation of the Nordic process industries share significant similarities with mission-oriented approaches, thus offering lessons for contemporary policy design. The thesis studies three cases in the Nordics, biofuels in Finland and Sweden, and the Swedish net-zero industries transition, which offer opportunities to understand what policymakers can and cannot accomplish when designing and implementing mission-oriented policies in sustainability transitions.

The three cases in the Nordic process industries illustrate that mission-oriented policymaking in sustainability transitions requires coordination across multiple policy fields. Analogously, addressing other types of societal missions, such as urban areas or soil, will likely require the multiple policy fields. In the Nordic cases, the combination and sequencing of policies mattered for shaping the direction of innovation and industry transformation. The cases show that differences in policy mix design and sequencing across the cases influenced how actors within the system behave and interact, structure their activities, how policy feedback loops emerged that contribute to the overall dynamics of the system, and in turn influenced the phase-out of technologies and uptake of innovations (Figure 2).

However, the direct applicability of the Nordic model elsewhere could be limited, due to socio-economic, political, and environmental contexts that may not be directly applicable to other regions. For instance, the Nordics have a strong emphasis on sustainability, high levels of public trust in the government, and robust welfare systems that create a conducive environment for implementing ambitious policies (e.g., Carlsson and Stankiewicz 1991). Moreover, the effectiveness of the combination and sequencing of policies in the Nordic cases has been closely tied to their specific governance structures, including collaborative approaches among government, industry, and academia. Other countries may have different governance dynamics, which could affect the implementation and outcomes of similar policy mixes. Therefore, while the principles of policy combination and sequencing may be relevant, the specific strategies may need to be adapted to fit different governance contexts. In addition, the process industries in the Nordic countries have distinct characteristics, such as a focus on advanced biofuels and a commitment to reducing greenhouse gas emissions. The generalisability of the findings may be limited when applied to other industries or

sectors with different technological, economic, or environmental challenges. For example, the strategies that work for biofuels may not be directly transferable to missions like urban areas or soil. Further work is needed to test and refine the observed patterns in other regions and sectoral contexts. While the specific outcomes of the Nordic cases may not be universally applicable, the underlying lessons regarding the importance of policy coherence, stakeholder engagement, and adaptive governance can be valuable for other regions. Policymakers in different contexts may draw on these principles to inform their own strategies, even if the exact policies and approaches differ.

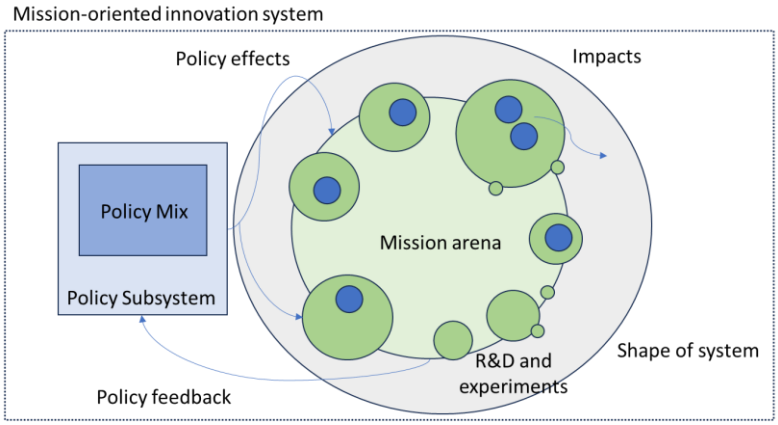

Figure 2: Illustration of the key dynamics in transition processes: policy mixes create policy effects that influence actors (green) and experiments (blue) in the mission arena, which influence the shape of industry (impacts), and in turn create policy feedback (Own illustration, inspired by Edmondson et al. 2019, Nevens and Roorda, 2014).

The findings presented in this thesis extends existing research on policy mixes in sustainability transition that highlights the importance of policy processes and policy mix design for technological change (Huang, 2019; Rogge and Reichardt, 2016; Söderholm, 2020; Zepa and Hoffmann, 2023) with a focus on the impacts of policies in relation to long-term societal goals (cf. Kern and Rogge, 2018). This thesis departs from transition studies on policy feedback (Edmondson et al., 2020a) and draws on insights from studies on actors in sustainability transitions (de Haan and Rotmans, 2018; Hellsmark and Jacobsson, 2009; Markard and Truffer, 2008b) and directionality (Andersson and Hellsmark, 2024) to explicitly link policy mixes, policy effects and feedback to the long-term impacts on production and consumption patterns. The focus on the types and roles of actors helps to understand how policies influence the strategies and behaviours of actors and if these responses are on track with the long-term societal goals. The work presented in this thesis shows how the focus on the types and roles of actors within a system helps to understand the influence of policies on their strategies and behaviours. The responses of actors to missions can align with long-term societal goals, such as reducing carbon emissions, increasing renewable energy uptake, or building new industries, thereby illustrating the interconnectedness of policy, actor behaviour, and societal outcomes.

On a more general level, the findings suggest that analysing the roles and types of actors, as well as their key challenges can help to understand the performance, evolution and policy feedbacks within systems and provide an entry point for mission-oriented policymaking (Kanger et al., 2020). The cases show that analysing the roles and challenges of actors within innovation systems helps to understand how these systems function and evolve. This understanding can serve as a foundation for developing effective, mission-oriented policies that support innovation and transformation and address the specific needs of various actors, leading to improved outcomes for the entire system. Drawing on insights from studies on policy feedback, sustainability transitions, and intervention points (Edmondson et al., 2020a; Kanger et al., 2020), policymakers could leverage knowledge of the shape, feedback dynamics, and characteristics of systems to test the influence of different instruments on system transformation and help set strategic priorities. Moreover, the findings may also be of relevance for studies addressing the monitoring and evaluation of mission progress and guide policymaking in adjusting policies (Haddad and Bergek, 2023; Penna et al., 2023). The thesis extends the focus from the outcomes of directionality (e.g., Andersson and Hellsmark, 2024) to capturing policy feedback and system dynamics. Moreover, studying the compositions, roles and challenges of actors also helps to understand key blocking factors in the system, e.g., which factors are blocking or hindering actors in their activities. These could be specific to a technology, such as lacking niche markets for scaling advanced biofuel production plants or cutting across multiple sectors and solutions, such as a lack of coordination and interactions across sectors, actors, and technologies.

In addition, the findings also provide a starting point to discuss key policy challenges for active mission management to influence the direction, speed, and completeness of transformations. The complexities and uncertainties inherent in societal missions underscore the relevance of active mission management, requiring substantial political capabilities to navigate policymaking. Similarly, Rotmans et al. (2001) have argued that capabilities among policymakers are key to effectively managing transitions, combining flexible goals with collective learning and iterative adjustments based on ongoing feedback and changing circumstances.

Building on the empirical cases, this thesis outlines key policy challenges for mission-oriented policies in sustainability transitions. More specifically, departing from the analytical framework outlined in section 2, the following text discusses what might be key policy challenges throughout policymaking in a societal mission context (Figure 3). These challenges are likely relevant throughout the entire process of societal missions.

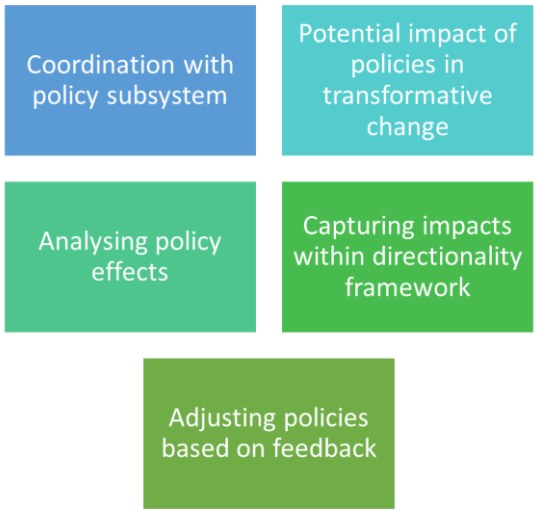

Figure 3: Key challenges in managing missions in sustainability transitions using the analytical framework outlined in section 2, based on insights from the empirical cases

A key challenge concerns coordination within the policy subsystem. Sustainability transitions often cut across multiple sectors and solutions, involving multiple government agencies, each with its own mandates, priorities, and regulatory frameworks, as well as international organisations (e.g., Huang, 2019). This fragmentation can lead to inconsistencies and conflicts in policy objectives, making it difficult to achieve coherent and coordinated action across policy areas and avoid duplications.

The cases illustrate that effective cross-sectoral coordination may need one organisation to take the lead. In the Finnish biofuels case, for example, the Ministry of Economic Affairs and Business coordinated the integration of industrial, innovation and market mechanisms. In the Swedish net-zero industries case, the innovation agency Swedish Energy Agency owns the "mission". Inverted from the Finnish example, monitoring and evaluating the dynamics with innovation networks (e.g., barriers experienced by different network actors in IS), and engage in collaborative efforts across subsystems. In contrast, the strong involvement of the Swedish government in the biofuel policy made it difficult to maintain momentum for coordinated action over time due to political cycles and changing priorities. In addition, limited coordination across subsystems also created problems.

Policy challenges will likely also involve competing interests and stakeholder conflicts. The cases illustrate that public and private sector actors often have conflicting interests and priorities. Engaging diverse groups while managing competing interests can complicate the policymaking process, making it challenging to build consensus around strategic goals.

Another challenge concerns the design of policy mixes. Societal missions, such as addressing climate change or public health, may require a diverse set of policy instruments that target different aspects of the problem. The cases illustrate that understanding how these instruments work together and add to pre-existing policies, can be challenging. For instance, policymakers may not fully understand how

different elements of a policy mix will interact or the potential impacts of these interactions on technological change and sustainability objectives.

In addition, the cases also show that economic conditions, technological advancements, and actor behaviours and strategies can all shift, requiring policymakers to adapt their policy mixes continuously. This adaptability can be difficult to achieve, especially when there is a lack of clear feedback mechanisms.

Challenges will likely also occur related to the effects of policies. As illustrated in the cases, different organisations within an industry may have distinct cultures and operational practices, leading to varied interpretations of the same policy. Policymakers face the challenge of managing these interpretations to ensure that policies achieve their intended outcomes. This requires effective communication and engagement with industry stakeholders to align expectations and objectives.

Closely related, policymakers may experience challenges to ensure that short-term changes in innovation and transitions align with long-term societal goals, such as sustainability and energy independence. Shaping the emergence and development of domestic value chain segments is crucial for achieving societal missions. However, the cases suggests that managing the interplay between market mechanisms and industrial innovation policy is complex. Policymakers must navigate the dynamics of value chain formation, ensuring that domestic firms can compete effectively and innovate in the face of global competition.

Finally, another policy challenge concerns policy feedback. Policies can create feedback loops that reinforce certain behaviours or directionality outcomes, which may not always be desirable. For example, policymakers in Finland successfully promoted advanced biofuels production, which lead to increased investment of incumbent industry firms in that area, but it also diverted attention and resources away from other potentially beneficial technologies. Thus, it is important to be aware of emerging feedback loops to avoid locking in suboptimal solutions.

In addition, actor often pursue different strategies and behaviours in policy processes, often linked to power and access to resources (e.g., Gomel and Rogge, 2020). This may make it challenging for policymakers to balance interests and ensure that marginalized voices are heard and considered. For example, there is a risk that close collaboration with incumbent industry actors may lead to narrow policy outcomes that prioritise specific industry interests over broader societal and environmental goals. This challenge highlights the need for a balanced approach that considers diverse stakeholder perspectives.

6.3 Improvements of the innovation system approach

The second question of the thesis asked how the policy process and policy mix design can be improved to better align with mission objectives.

In line with prior research (e.g., Bergek, 2019), the thesis finds that systems thinking provides a useful starting point to study innovation and guide policymaking. This thesis complements previous research on mission- and transition-oriented frameworks (Andersson and Hellsmark, 2024; Elzinga et al., 2023; Penna et al., 2023; Wanzenböck et al., 2020; Wesseling and Meijerhof, 2023) with an analytical framework that addresses the role of policymaking in transformative changes.

Specifically, the thesis combines previous systems perspectives (e.g., TIS, MLP) into one analytical framework to describe and analyse production and consumption patterns, and links the direction of change in such patterns to the role of policy. The framework combines a structural boundary, which identifies the key actors, technologies, and institutions, with a functional boundary, which defines the activities and processes that these elements perform. The thesis applies this analytical framework to the empirical setting of the transformation in the Nordic process industries. The cases demonstrate the usefulness of this approach for studying how policy processes and policy mix design can shape the direction of industry transformation. The case analyses offer insights into changes in production and consumption patterns, system dynamics, and how policy can shape the direction of change by targeting specific intervention points. These findings suggest that the synthesised view between structural and functional boundaries matters. By linking who is involved with what they do, the analyses provide a more comprehensive understanding of how policy-driven transitions progress.

In comparison to previous system perspectives (cf. Markard and Truffer, 2008a), this synthesised view allows for a more holistic perspective of how systems operate and transitions progress. Previous approaches often focus on specific elements on policy-driven transitions, such as policy- (e.g., Wanzenböck et al., 2020; Wittmann et al., 2020) and innovation-related processes (e.g., Elzinga et al., 2023; Wesseling and Meijerhof, 2023) and outcomes (e.g., Andersson and Hellsmark, 2024) within a directionality framework. In contrast, this thesis offers a more comprehensive picture, by integrating configurational and systems perspectives within a directionality framework. The cases demonstrate that combining functional and system boundaries with policy mixes and policy feedback allows for a comprehensive exploration of how policy-driven transitions unfold within various contexts.

By doing so, this thesis addresses research calls (e.g, Weber and Truffer, 2017) to improve the IS approach for addressing grand societal challenges and related policymaking. The conceptual work and empirical evidence presented in the thesis provide building blocks for outlining an innovation systems approach, which could be called “innovation-oriented sociotechnical system”, taking inspiration from

the innovation ecosystems concept (e.g., Granstrand and Holgersson, 2020; Ritala and Almpanopoulou, 2017). In contrast to other ideas proposed in the literature, this "innovation-oriented sociotechnical system" is not a temporary system, but it evolves and adapts over time as technologies are phased out and new innovations are introduced.

The findings obtained in this thesis may also help to support the design, implementation, and evaluation of policy mixes to guide the production and consumption patterns toward long-term societal goals. While the analytical framework has been used to study historical and ongoing transformations in this thesis, it could also provide a useful starting point to guide policymaking in less mature policy fields and missions. Building on lessons from the work conducted in this thesis, Table 2 presents an actionable framework that outlines several guidelines on how to use the innovation-oriented sociotechnical systems approach to help align policy processes and policy mix design with societal missions. In practice, the analysis is likely an interwoven and iterative process, and analysts may need to go back and forth between the steps.

The guidelines should be of interest for scholars in the sustainability transitions field, and for policymakers involved in mission-driven innovation and transition processes. This thesis has no ambitions to derive specific recommendations on how this could be done but seeks to contribute to the discussion around critical role of system-based foresight in guiding policymaking in the context of societal missions. Further work is needed to develop, test, and refine the steps outlined in the guidelines.

Table 2: Summary of the proposed steps to design mission-oriented innovation policy

Overarching steps	Key analytical steps
Translating challenges to mission goals	Step 1: Defining the problem
	Step 2: Defining solutions
Designing and implementing policy mixes for transformative change	Step 3: Pathways, system dynamics, and key intervention points
	Step 4: Designing effective policy mixes
Monitoring, evaluating, and adjusting policy mixes	Step 5: Mapping the responses of actors to missions
	Step 6: Evaluating mission progress
	Step 7: Adjusting policies

Step 1: Defining the problem

This step aims to define the problem a mission is trying to address. It helps ensure that the mission problem definition is context-sensitive and responsive to the sectoral systems it seeks to influence.

Using the analytical framework outlined in Section 2, the problem definition could be carried out by delineating the structural boundaries of the system in focus. It is worth noting that system boundaries can be defined in many ways. Taking the Swedish net-zero industry transition as an example, Figure 3 illustrates the differences between the structural boundaries derived from the overarching policy ambition of net-zero emissions and the narrow translation into current policy strategies. It depends on the specific aims of a study and which approach might be more suitable.

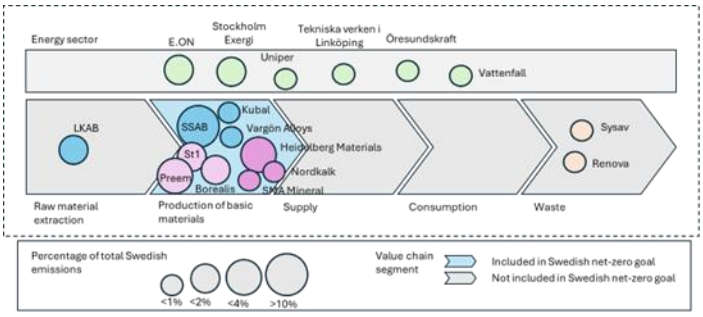

Figure 4: Delineating structural boundaries: comparison of system boundaries delineated by value chain segments included in the Swedish net-zero goals (marked blue) or according to the industry value chain (additional grey fields) (delineation of process industry value chain inspired by Bergek et al. 2023b

Step 2: Defining solutions

In this step, analysts need to define the functional boundaries of the mission. Functional boundaries delineate the specific functions or roles that the components of the innovation system perform in relation to the innovation process. This includes the activities and processes that contribute to the development, diffusion, and utilisation of innovations. This helps to concentrate the analysis on the most significant components that influence mission progress. As illustrated in the empirical setting, functional boundaries may have a nested structure, including a range of low-carbon solutions.

After initially setting functional boundaries, it is important to remain open to feedback and adapt the definitions as new insights, technologies, or political priorities emerge. This iterative process allows for continuous improvement in understanding the innovation system.

Step 3: Pathways, system dynamics, and key intervention points

The composition of actors, their past behaviours, and the strategies they employ are closely linked to the pathways that socio-technical systems can take. These elements interact dynamically, influencing the direction and pace of transitions. By analysing these connections, policymakers can better understand the factors that facilitate or hinder change, allowing for the design of more effective interventions to promote sustainability.

The work presented in this thesis illustrates that analysing historical transformation processes can help identify key moments and decisions that shaped the trajectory of biofuel industries in the Finnish and Swedish cases, providing insights for future policy design. In both countries, several different patterns of domestic value chain segments could be observed, however, with differences in terms of scale and numbers (Figure 5). By comparing cases, researchers can identify specific intervention points that have been effective in facilitating transitions in different contexts. This identification is crucial for understanding where targeted actions can lead to significant changes in pathways and systemic dynamics.

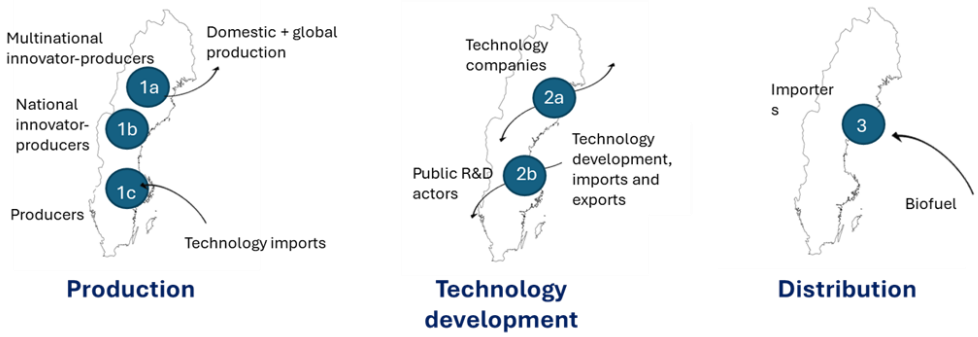

Figure 5: Illustration of potential configurations of domestic value chain segments emerging in a country (based on findings in appended Paper 1)

Understanding the links between actors, past behaviours, and strategies allows for scenario planning, where different future pathways can be explored based on varying actor compositions and strategic choices.

Step 4: Designing effective policy mixes

Learning from past transitions can provide valuable insights into effective policy mix design, particularly in the context of fostering challenge-led missions like industry decarbonisation. The biofuel cases, for example, suggest that effective policy design for missions towards net-zero industries requires a comprehensive, flexible, and adaptive approach that engages stakeholders, incorporates feedback, and aligns with long-term goals. Based on historical cases, it also becomes possible to derive lessons about the role of design features of individual instruments, e.g., R&D programmes, the selection and combination of market mechanisms and industrial innovation policies, or the integration of stakeholder feedback. The cases also highlight the importance of promoting collaboration among different levels of government and between public and private sectors to ensure that policies are coherent and aligned across various domains.

Models could also play a crucial role in testing the impact of policies on intervention points, system dynamics, and pathways in mission-driven innovation processes (Köhler et al., 2019). Models can

help identify which intervention points are most sensitive to policy changes. By simulating the effects of different policies on these points, researchers can determine where targeted actions are likely to yield the most significant impact on system dynamics and transition pathways. Moreover, by creating different scenarios based on varying policy interventions, models can help predict how changes in one part of the system (e.g., a new regulation or incentive) might affect other parts.

Step 5: Mapping the responses of actors to missions

This step aims to assess the structural components of the incumbent sectors and the emerging technologies within the system, including the actors, networks, and institutions, by evaluating their roles, relationships, and contributions to innovation dynamics. This analysis helps identify key players and their influence on the innovation process. It also provides a first understanding of gaps and factors hindering system development.

Using the analytical framework outlined in section 2, the appended papers illustrate how the responses of actors to policies can be captured.

Step 6: Evaluating mission progress

The primary goal is to assess how existing policies influence subsequent policymaking and the responses of actors within the innovation system. By evaluating feedback loops, researchers and policymakers can gain insights into the effectiveness of policies in achieving their intended outcomes, such as promoting technological innovation or fostering industrial growth. This involves an analysis and evaluation of emerging feedback loops within a system, and to derive process goals in relation to intervention points.

The case of biofuel technologies in Sweden shows that by examining the roles, interactions, and relationships among key actors in the biofuel system, it becomes possible to gain insights into how technologies are generated, developed, and brought to market. By tracking how actors respond to existing policies and how these policies impact technological development and direction, it is possible to identify misalignments between policy objectives and actual outcomes.

The cases suggest that combining back-casting with a forward-looking lens could be a tool to navigate complexity by providing a structured approach. Backcasting allows analysts to evaluate the current state of affairs and identify barriers that may hinder progress toward the desired future, i.e., misalignments between policy ambitions and the net-zero strategies of incumbents (in relation to the benchmark indicators from Step 1). Looking forward involves identifying system weaknesses by analysing interactions, resource allocation, institutional support, barriers to entry, feedback

mechanisms, performance metrics, contextual influences, knowledge gaps, fragmentation, and stakeholder engagement. Together, these steps help pinpoint specific areas within a system and derive process goals concerning key intervention points.

On a methodological level, the analysis conducted in this thesis draws on a qualitative content analysis of newspaper articles that have been coded and analysed using the conceptualisation of policy feedbacks, actors and technologies within systems. More advanced tools, such as machine learning in combination with social network analysis, could decrease analysis times and enable real-time monitoring of mission progress.

Step 7: Adjusting policies

Based on the revealed specific bottlenecks and gaps, stakeholders—including policymakers, industry leaders, and researchers—can design targeted interventions to address these issues. This could involve providing funding, creating incentives, or fostering collaborations that specifically aim to overcome identified barriers, thereby enhancing the overall system.

By focusing on intervention points, policymakers can establish feedback mechanisms to assess the effectiveness of their adjustments. This iterative process allows for continuous learning and adaptation, ensuring that policies remain relevant and effective over time. One way to support the implementation of policies could be to set up monitoring systems to track the effectiveness of policies and their impact on the identified intervention points and pathways. This data can inform ongoing adjustments and improvements.

7 Conclusions

This thesis addresses the role of policymaking in achieving societal missions. To achieve this task, the thesis has developed an analytical framework that extends the innovation systems approach to link policy to changes in the shape of innovation, production, and consumption patterns. The thesis uses this analytical framework to study three cases in the historical and ongoing transformation of the Nordic process industries. These countries have implemented policies with an implicit mission-orientation since an extended period, and thus, should offer insights into the role of mission-oriented policymaking in sustainability transitions.

The cases show that in the Nordic process industries, the combination and sequencing of market mechanisms, innovation and industrial policies mattered for the direction and development of innovation and industrial development. These findings add to studies on mission-oriented and transformative policies in sustainability transitions by providing evidence how policies have shaped the direction and development of innovation and industrial transformation across multiple cases. The cases also reveal challenges for policymakers, for example, on how to anticipate the strategies and behaviours of innovation and industry actors or how to orchestrate the emergence of multiple value chains. Building on the derived analytical framework and lessons from the empirical studies, this thesis proposes some guidelines on how systems could be studied to support the alignment of policy processes and policy mix design in societal missions.

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Overview of appended papers

Paper 1: Shaping domestic industry growth in global sustainability transitions: a comparative analysis of biofuels in Finland and Sweden

Authors: Barbara Hedeler, Hans Hellsmark, Patrik Söderholm, Björn Sandén

Contributions: Hedeler had the lead in writing the paper. All authors have taken part in developing and refining the idea of the paper. Together with Donner-Amnell and Hellsmark, Hedeler conducted the interviews. Hedeler also took the lead in analysing and interpreting the data with feedback from all co-authors, as well as writing the manuscript under supervision, with feedback and input from all authors.

Status: final draft

Paper 2: Policy mixes and policy feedback: Implications for green industrial growth in the Swedish biofuels industry

Authors: Barbara Hedeler, Hans Hellsmark, Patrik Söderholm

Contributions: The paper is co-authored between Hedeler, Hellsmark & Söderholm. All co-authors took part of developing the idea for the paper. Hedeler had the lead in writing the paper. Hedeler conducted the empirical analysis and wrote the manuscript with feedback from all authors.

Status: Published in Renewable and Sustainable Energy Reviews (2023)

Paper 3: Leaders and Laggards: The Role of Incumbents in Transformative Policy Missions

Authors: Hans Hellsmark, Johnn Andersson, Barbara Hedeler

Contributions: The paper is coauthored Hellsmark and Andersson. Hellsmark has the lead on this paper, although all authors have taken part of developing the idea for the paper. Hedeler took the lead on writing earlier draft versions of the paper, which have been presented at two conferences. The paper has since then been substantially re-worked and extended with additional data, with Hellsmark taking the lead on the revisions. Hedeler's role in the final version of the article was to conduct and write one part of the empirical analysis, as well as comment on and review other parts of the paper.

Status: under review

Paper 4: Cutting across sectors, solutions and goals in transformative missions: the roles of key actors in the net-zero transition of the Swedish industries

Authors: Barbara Hedeler, Hans Hellsmark

Contributions: The paper is co-authored by Hedeler and Hellsmark, where Hedeler has the lead on developing and writing the paper. Both authors contributed to creating the idea for the paper. Hedeler wrote the main part of the manuscript, with feedback and inputs from Hellsmark.

Status: final draft