THESIS FOR THE DEGREE OF LICENTIATE OF PHILOSOPHY

Policy Mixes for Industrial Transformation

Lessons from Finland and Sweden

BARBARA HEDELER

Department of Technology Management and Economics

CHALMERS UNIVERSITY OF TECHNOLOGY

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BARBARA HEDELER

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Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

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Chalmers University of Technology

Abstract

An accelerated transition of the existing industry sectors towards low-carbon and renewable energy technologies is crucial to achieving global climate targets and national net zero emission commitments. This thesis departs from the notion that many governments increasingly emphasise the possibilities of combining such a transformation with domestic "green growth". Recent research suggests that policymakers can influence innovation and transition processes through the implementation of transformative innovation policies, including a mix of instruments oriented towards climate and industrialisation goals. At the same time, scholars have stressed that the design and implementation of policy mixes play a key role in their effectiveness. Despite these advances, there is a lack of studies addressing the outcomes of such policy mixes in the context of transformative change in the industry.

This licentiate thesis aims to enrich the current understanding of the impact of policy mixes on industrial transformation processes. To this end, this thesis builds on three historical case studies of industrial transformation in the Nordic countries. It combines qualitative interviews with secondary data and social network analysis to reconstruct how the implemented policy mixes have influenced the industrial transformation over an extended period (2003-2022). Theoretically, this thesis departs from the innovation systems approach and draws on insights from studies of transformative innovation policies, mission-oriented innovation systems and value chains.

The thesis contributes to a more advanced understanding of the underlying processes by which policy mixes influence industrial processes towards the targeted transformative change. First, the thesis contributes with a typology of value chains, which describes and explains how differences in the type, design and implementation of policy mixes could lead to alternative value chain developments. Second, the thesis develops a process model that describes and explains how policy feedbacks affect the evolution of policy mixes and the subsequent emergence of renewable energy technologies and industrial structures. Third, the thesis contributes to the understanding of the impact of collaborative R&D programs directed toward promoting low-carbon innovation and experimentation in the established industry by investigating the role of the main Swedish industrial emitters in one policy-driven R&D network.

Keywords: industrial transformation, value chains, transformative innovation policies, policy mix, biofuels, process industry

List of appended papers

This thesis builds on the work of three appended papers:

Hedeler, B.; Donner-Amnell, J.; Hellsmark, H.; Söderholm, P.: Between national policy mixes and global innovation dynamics: a typology of value chains. Draft.

Earlier versions have been presented at the IST Conference 2020, the NEST Conference 2020, and the ETH PhD Academy 2020.

Hedeler, B.; Hellsmark, H.; Söderholm, P.: Fostering domestic green industry growth in the presence of policy feedback: the case of the Swedish Biofuels Industry. Under review in Renewable and Sustainable Energy Reviews.

Earlier versions of this paper have been presented at the ECPR Joint Sessions 2021 and the IPPA Conference 2021.

Hedeler, B.; Andersson, J.; Hellsmark, H.: Networks and technologies towards zero emissions in the industry: the case of Swedish R&D networks in policy-driven mission-oriented industrial transformations. Draft.

Accepted for presentation at the IST Conference 2022.

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1 Introduction

1.1 Transitioning industry towards net zero emissions

As a result of the 2015 Paris climate agreement, governments worldwide are increasingly committing to achieving net zero emissions within short time frames. Examples include the Finnish net zero target by 2035, and the Swedish goal to reach net zero emissions by 2045, as well as negative emissions after that year. To achieve such decarbonisation goals, countries require a deep transformation of established production and consumption systems. With increasing progress in the energy and transport sectors through the large-scale diffusion of renewable energy technologies and electric vehicles, considerable attention is now devoted to harder-to-abate sectors, e.g., agriculture, aviation, shipping and industry (Davis et al., 2018). The decarbonisation of the latter is associated with major challenges, not least as limited knowledge exists about the availability and feasibility of potential decarbonisation paths.

One of such harder-to-abate sectors is the process industry. The conversion of natural resources is based on energy and carbon-intensive processes. Globally, in 2020, industry accounted for roughly 20% of greenhouse gas emissions (World Resources Institute, 2022). Notably, the percentage of industrial emissions in certain countries is higher, including Sweden, where industrial emissions are responsible for approximately one-third of the total territorial emissions (Swedish Climate Policy Council, 2022). While there has been strong resistance from important parts of the industrial sector (Victor, 2012), the importance of addressing emissions from industrial processes is increasingly acknowledged on a global scale. Still, recent research suggests that the ongoing transition in the industry is too slow (IPCC, 2022).

As current industrial processes provide only a limited potential for emission reductions, a deep transformation of established industrial processes is required to reduce industrial emissions to zero (Wesseling et al., 2017). Many low-carbon technologies exist at small scales, such as carbon capture and storage of industrial emissions or hydrogen as a substitute fuel in industrial processes. However, much uncertainty still exists about their technical feasibility, not least since their large-scale deployment depends on large-scale infrastructure and a sufficient supply of renewable energy and green hydrogen (Davis et al., 2018; Hermwille et al., 2022). At the same time, recent studies on the industrial transition in the sustainability transitions literature have stressed that the sectoral structure of established industries represents a major barrier to a rapid transition (e.g., Bauer et al., 2022; Dewald and Achternbosch, 2016; Nilsson et al., 2021; Wesseling et al., 2017). As industrial products are traded on international commodities markets, companies typically operate with highly efficient processes amid low-profit margins to be competitive (Wesseling et al., 2017).

While decarbonised industrial processes can lead to process improvements, they do not necessarily result in decreased costs. They can lead to “product improvements” when customers are willing to pay extra for low carbon. Still, previous research has emphasised that a rapid and large-scale industrial

transition will depend on the implementation of comprehensive policies (Hermwille et al., 2022; Lilliestam et al., 2020). Although first cross-national political negotiations have been launched, one example is the joint statement between the European Union and the US to create a market for aluminium and steel (United States and European Union, 2021), recent research suggests that the actual implementation of policies has been relatively slow (Nilsson et al., 2021). Moreover, enabling net zero emissions in the industry can also allow new paths towards zero emissions. Indeed, national governments increasingly seek to reconcile climate policies with broader socio-ecological objectives and pursue new economic opportunities under the "green growth" narrative (Fankhauser et al., 2022; Meckling and Allan, 2020). Hermwille et al. (2019), for example, have argued that while European countries are leading the development of decarbonised steel technologies, additional efforts will be needed to keep large shares of value chains as the major share of global demand is projected for emerging and developing countries.

Designing public policies capable of inciting and accelerating transformative change is an increasingly important area in the literature at the intersection of innovation policies and sustainability transitions (for a recent review, see Haddad et al., 2022). Traditionally, these scholars have subscribed to the belief that innovation policies should provide the right conditions for innovation. However, for achieving the transformative change required for grand societal challenges, including reducing carbon emissions to tackle climate change, it has been argued that governments need to take on a more active role (Mazzucato, 2016; Schot and Steinmueller, 2018).

In this view, innovation policies, commonly referred to as transformative innovation policies play a crucial role in providing adequate conditions to increase the rate of innovation and align innovation with the targeted direction (Mazzucato, 2018; Schot and Steinmueller, 2018). As policy-led directionality is inherently linked to prioritising and selecting societal challenges and potential solutions (Janssen et al., 2022), directionality as a concept has received considerable attention in recent years (e.g., Grillitsch, 2020; Wanzenböck et al., 2020). Given that innovation processes are inherently uncertain and complex, research has highlighted the importance of "opening up and closing down" multiple pathways in parallel (Stirling, 2008). Much of the research has, up to this point, focused on the processes leading to policy-led directionality (cf. Haddad et al., 2022). One central conclusion of these studies is that it is vital to include multiple actor networks in the relevant policy processes (e.g., Wanzenböck et al., 2020). More recently, a nascent debate has emerged on the innovation outcomes of directionality (e.g., Andersson et al., 2021; Andersson and Hellsmark, 2022; Grillitsch, 2020). While these studies highlight that any solution space can be defined by a bundle of value chains (Andersson et al., 2021), little insight is provided into the impact of transformative policies on forming such value chains.

Investigating the role of institutions in the co-evolution of technologies and industrial structures has been a continuous theme within the innovation systems literature (Carlsson and Stankiewicz, 1991; Freeman, 1987; Malerba, 1996; Nelson, 1995, 1994). These scholars argue that policies affect the creation and selection of new technologies and industrial structures. At the same time, however, institutions are influenced by technological change and industrial actors, which subsequently affect how institutions and policies evolve and with recurring effects on technologies and industrial structures (Jacobsson and Lauber, 2006). More recent research has introduced a refined understanding of institutions and policies. Building upon the public policy literature, these studies investigate innovation policies through the lens of policy mixes (for a recent review, see Sewerin, 2020). A policy mix can be understood as a combination of elements (e.g., strategic goals, instruments) and policy processes (Rogge and Reichardt, 2016). Research along these lines has shown that to understand the effectiveness of policy mixes, it is vital to consider how they are designed and implemented. For example, Reichardt and Rogge (2016) found that German technology providers perceived the national offshore wind policy mix as credible, which helped overcome temporarily lacking instruments.

While much of the research, thus far, has focused on policy mixes directed at the development and diffusion of novel technologies in a sustainability transition context, only a few studies have focused on policy mixes addressing green growth goals. With the increasingly global distribution of renewable energy value chains (Hipp and Binz, 2020), these studies typically focus on the impact of policy mixes on the localisation of value chain segments, such as the R&D sector and the technology adopters (Reichardt and Rogge, 2016), manufacturers (Rogge and Dütschke, 2018; Rogge and Schleich, 2018), or local renewable energy value chains (Matsuo and Schmidt, 2019).

However, innovation system scholars have emphasised the interconnectedness and interdependencies in the evolution of value chains, and they suggest that policymakers may need to support cross-sectoral dynamics (Malhotra et al., 2019; Stephan et al., 2017). At the same time, previous studies have stressed multiple modes of interaction, ranging from competition to collaboration, between value chains (Sandén and Hillman, 2011). Indeed, recent research indicates that power imbalances between competing actor networks can shape the competition for political resources (Gomel and Rogge, 2020). Up to this point, however, it remains somewhat unclear how countries' policy mixes evolve and how these mixes affect the emergence of domestic value chains. Moreover, recent research has stressed that for industrial transformation, many different technologies and value chains need to be promoted in parallel (Nilsson et al., 2021). Besides the emergence of new technologies, other pathways are feasible, such as reorientating established value chains (Geels et al., 2016). However, much uncertainty still exists about the impact of policy mixes on the industrial transformation.

1.2 Purpose and research questions

This thesis seeks to provide novel insight into the effects of transformative innovation policies on the targeted change processes in the established industry by studying how different policy mixes have influenced past industrial transformations. Specifically, the purpose of this thesis is to analyse the interplay between policy mixes and industrial transformation processes directed towards net zero emission or other similar mission-oriented goals.

Throughout this thesis, the term transformative innovation policy is used to describe the overarching policy framing. There is a variety of definitions of the term transformative innovation policies. This paper will use the definition suggested by Haddad et al. (2022), who see it as an overarching term to describe directed innovation policies. Following these authors, this term includes different conceptual ideas such as transition-oriented or mission-oriented innovation policies or combinations of both. Transition-oriented policies emphasise the importance of taking a "broader understanding of the innovation process and its relevant actors, activities and modes of innovation" (Diercks et al., 2019, p.886). In contrast, mission-oriented innovation policies tend to employ a narrower understanding, which implies that these policies primarily focus on the "commercialisation of science" (Diercks et al., 2019, p.885).

As emphasised in prior studies, countries pursue different approaches to implementing transformative innovation policies (e.g., Chataway et al., 2017). Nevertheless, it is commonly recognised that a combination of strategic goals and instruments in so-called policy mixes is needed to enact such transformative innovation policies (Schot and Steinmueller, 2018; Weber and Rohracher, 2012). Building upon Rogge and Reichardt (2016), the term policy mix will be used to refer to the combination of strategic elements (e.g., goals, roadmaps), instrument mixes, and policy processes.

Hence, when discussing the theoretical framing of policy interventions, this thesis refers to transformative innovation policies, while the policy mix concept is used to describe and analyse actual policy interventions.

This thesis combines and builds upon the research of three appended papers. Each paper presents a historical case study analysis and focuses on different aspects of the link between transformative innovation policies and transitions in the process industry. Table 1 gives an overview of the research questions addressed in each paper. Paper 1 focuses on the effects of transformative innovation policies on forming value chains associated with emerging technologies in the biofuel field. As an extension of Paper 1, Paper 2 investigates how policies evolve, understood through the lens of policy feedback theory, and examines the subsequent effects on industrial development associated with emerging biofuel technologies. Paper 3 takes the perspective of the transition of the established industry and investigates the impact of a transformative R&D program on the innovation behaviour of the main industrial emitters of carbon dioxide.

Table 1: Overview of the research questions addressed in each paper

Paper	Title	Research Questions (RQ)
1	Between national policy mixes and global innovation dynamics: a typology of value chains	RQ1: How have the biofuel policy mixes been designed and implemented in Finland and Sweden between 2003 and 2020? RQ2: How have the respective national policy mixes influenced the formation of innovative activities along biofuel technology value chains in Finland and Sweden between 2003 and 2020?
2	Fostering domestic green industry growth in the presence of policy feedback: the case of the Swedish biofuels industry	RQ3: What are the causes of the evolution of the Swedish biofuel policy mix over time (2003 to 2020)? RQ4: What are the effects of the evolution of the Swedish biofuel policy mix on the technologies and industrial structures emerging in Sweden?
3	Networks and technologies towards zero emissions in the industry: the case of Swedish R&D networks in policy-driven mission-oriented industrial transformations	RQ5: What are the effects of the Swedish innovation policy instrument *Industriklivet* on experimentation with emerging technologies, such as hydrogen and carbon capture, across the main emitters in the Swedish industry?

1.3 Research scope

This thesis investigates the impact of transformative innovation policies on industrial transition processes through the lens of innovation systems. More specifically, it focuses on the meso-level of innovation systems by connecting and analysing the interaction between policy, industrial actors and the different technical solutions pursued.

The research follows a case-study design with an in-depth analysis of the impact of transformation innovation policies on the development of the Northern European industry. It focuses on a Nordic perspective as these countries have been affected by national climate policies in the past. For example, in 2003, Finland and Sweden implemented national policies targeted at the uptake of biofuels in the transport sector and the growth of domestic biofuel industries. In addition, these countries strive to achieve net zero emissions within relatively short time frames, putting additional pressure on the domestic industries.

To analyse the interplay between policy mixes and industrial transformation processes, this thesis has selected historical developments that can reveal novel insights about the impact of transformative innovation policy. The thesis does not provide an exhaustive overview of all possible technologies and pathways toward reducing industrial emissions to net zero levels.

2 Theoretical background

This thesis takes its theoretical starting point in the innovation systems approach. It suggests that the emergence of innovation systems supports the growth of industries (Freeman, 1987). Innovation systems enable the development, diffusion, and use of various emerging and new technologies through the interaction of actors, networks, and institutions (Carlsson and Stankiewicz, 1991). At its core, innovation systems are based on evolutionary principles of variety creation and selection and retention of viable alternatives, including actors, technologies, and products (Nelson, 1994). The past thirty years have seen increasingly rapid advances in the field of innovation systems. The following is a review of research streams on the theoretical underpinnings and the design and implementation of transformative innovation policies, industrial change, and the evolution of novel value chains. Building upon this literature review, the research outline of this thesis is concretised.

2.1 Theoretical underpinnings of transformative innovation policy

The innovation systems approach has a long-held interest in the role of policy for technological innovation and economic growth (Freeman, 1987; Lundvall, 1992). In this literature, the rationale behind the involvement of institutions and the implementation of innovation policy is that during the evolution of innovation systems, weaknesses and failures may occur which hinder the functioning of evolutionary mechanisms (e.g., lack of markets may hamper selection of viable alternatives and/or inadequate financial resources can impede variety creation) (Malerba, 1996). In turn, policymakers may try to address such weaknesses and failures by implementing innovation policies. Ultimately, the promotion of well-functioning innovation systems should increase the rate of innovation (variety creation), which subsequently increases the chances for the selection of viable alternatives (Malerba, 1996; Nelson, 1995). Research on innovation policies in an innovation system context has shown that several markets, technology, and system failures typically exist, thus requiring the implementation of a mix of instruments (e.g., demand-pull, technology-push, and systemic tools) (Borrás and Edquist, 2013).

In the context of sustainability transitions, studies of innovation policies have argued that additional failures regarding the direction of shifts may occur, so-called transformational failures (e.g., Weber and Rohracher, 2012). It has been argued that the transformative change required to achieve sustainability transitions differs from previous historical change processes since future innovations need to align with the desired goal of sustainability to achieve broader societal goals (Schot and Steinmueller, 2018; Stirling, 2008). Innovation is thus viewed as a "means to an end" rather than a goal in itself. Consequently, scholars have called for a paradigm shift and a new generation of 'transformative' innovation policies (Schot and Steinmueller, 2018). They emphasise that it is vital for innovation

policies to provide a normative direction for change (Diercks et al., 2019). This could mean that innovation policies are tied to broader societal goals. Such policies include the German *Energiewende* or the European Green Deal (Mazzucato, 2018).

At this point, different ideas exist on how such transformative innovation policies could be designed (Diercks et al., 2019). One central idea is the design of transition-oriented policies (e.g., Schot and Steinmueller, 2018). Originating from the transitions literature, these studies emphasise that for promoting transformative change, policies need to address several system failures (lack of directionality, policy coordination, demand-articulation, reflexivity) (Schot and Steinmueller, 2018; Weber and Rohracher, 2012). Studies have shown that these policies often include policies directed at emerging technologies and declining established carbon-intensive industries (Kivimaa and Kern, 2016; Reichardt and Rogge, 2016). Another central idea is implementing mission-oriented policies (Mazzucato, 2018). Grounded in economics, these studies propose the formulation of missions characterised by bold, well-defined goals that require ambitious and cross-sectoral innovation of a range of bottom-up solutions (Mazzucato, 2018). Research suggests that both ideas, albeit with different origins, have converged in recent years (Diercks et al., 2019; Haddad et al., 2022). For example, recent years have seen the take-up and use of 'missions' in the literature on innovation systems (Hekkert et al., 2020; Wesseling and Meijerhof, n.d.).

2.2 Design and implementation of policy mixes

Besides the progress made regarding the core and rationales of innovation policies, how the impact of innovation policies is studied in innovation systems research has also evolved. Much of the early work on innovation policies has focused on understanding the innovation dynamics created by different policy instruments (Bergek and Jacobsson, 2010; Borrás and Edquist, 2013). One notable exemption is Jacobsson and Lauber (2006), who broadened the view by considering how policies affect and are affected by innovation dynamics within innovation systems, i.e. the *politics of policy* (see also, for example, Malerba, 1996; Nelson, 1995)

Over time, scholars have started to adopt a broader view of innovation policies, highlighting the importance of considering the design, interactions, and interdependencies between policy instruments. For example, del Río (2014) has investigated the combination of green certificates and the European Trading System (ETS) to promote renewable energies. According to his work, green certificates tended to promote mature, low-cost renewable energy technologies. In contrast, the ETS supported the cheapest low-carbon technologies (at that time, renewable energy technologies were typically more costly than

other low-carbon technologies). Hence, both instruments supported different technologies rather than consistent support for the diffusion of renewable energy technologies (del Río, 2014)[1].

Scholars have called for a broader view of innovation policies through the lens of policy mixes, including both the objectives, instruments, and the processes through which policy mixes are implemented and adapted over time (Flanagan et al., 2011; Flanagan and Uyarra, 2016). Responding to these calls, Rogge and Reichardt (2016) have proposed a so-called 'policy mix concept', which defines the strategic elements (goals, roadmaps, instruments), the policy processes, as well as several concepts to describe the characteristics of policy mixes (e.g., how consistent or credible a policy mix is perceived to be). Building upon previous public policy studies (Howlett and Rayner, 2013, 2007), these scholars have introduced the concept of layering to the transitions literature to describe policy mixes that emerge over time. Layering can be understood as the amendment of instruments/ policy mixes once implemented and subsequent addition or removal of parts of policy mixes (Howlett and Rayner, 2013, 2007). While layering is often connotated with inconsistencies of the policy mixes, recent research has shown that subsequent layering of policy mixes can be an effective strategy to implement and ratchet-up climate policies (e.g., Meckling et al., 2017; Schmidt and Sewerin, 2019).

Recent empirical analyses have shown that the design of policy mixes and their characteristics in the combination affect how innovation processes unfold in innovation systems. For example, in the German innovation system for offshore wind, problems with the demand-side instrument were argued to hamper the market formation of that technology (Reichardt et al., 2016).

Other work has adopted a more dynamic perspective on the evolution of policy mixes and their impact on sociotechnical change. These studies draw from the policy feedback literature, which suggests that past policies affect the choices of subsequent policymaking (e.g., Pierson, 1993; Schattschneider, 1935). Edmondson et al. (2020), for example, have shown how the adaptation of the UK policy mix for zero carbon homes led to its ultimate failure over time, as support from actor groups profiting from the policy mix could not balance out the strength and scope of opposition from other actors.

Together these studies provide valuable insight into the link between policy mixes and industrial transformation. While few studies have addressed the link between the design and characteristics of policy mixes and the evolution of different value chain sectors in the country of the policymaker, too little insight is provided into the mechanisms and patterns underpinning the impact of policy mixes on value chain development.

[1] Now, green certificates schemes are redundant since the ETS supports mature renewables.

2.3 Industrial Transformation

Investigating industrial transformation through technological change is at the core of innovation systems studies. It has been argued that industries transform through the development and diffusion of new technologies (Dosi, 1984; Malerba, 1996). Within the innovation systems approach, research typically analyses the evolution of new industries by investigating the innovation dynamics delineated by emerging technologies, sectors, regions, or countries (Carlsson and Stankiewicz, 1991; Lundvall, 1992). In the light of pressing climate challenges and the implementation of transformative innovation policies, recent scholarship on innovation systems has turned towards a better understanding of the processes between industrial transformation and the development and diffusion of new and emerging technologies (e.g., Hekkert et al., 2020).

Research into innovation systems has started to build on insights from the broader transitions literature to understand how industries transform. These studies explain how sociotechnical systems change through the interaction between multiple levels (e.g., technological niches and incumbent regime actors) (Geels, 2002). Studies on innovation systems forming around societal missions aim to understand the structural components and dynamics of processes that drive the development in line with a mission towards a goal (Hekkert et al., 2020). To widen the analytical focus of innovation system studies, several changes have been proposed (Hekkert et al., 2020; Wesseling and Meijerhof, n.d.).

It has been suggested that the goal of a system should be defined based on a mission (Wesseling and Meijerhof, n.d.). Missions are typically formulated around existing problems, such as climate change or emission reduction, and require the development and deployment of solutions (Mazzucato, 2018). Depending on the breadth of the chosen goal/ mission, more or fewer restrictions are put on the solution space. For example, formulated as promoting wind power, the solution space is still open compared to promoting a specific kind of wind power.

Within this emerging literature, much of the research has so far focused on addressing conceptual challenges. Up to this point, however, we lack empirical insights into the policy-driven innovation processes across established industries. Transformative change, in this case, can be understood as slightly narrower than economic growth or general welfare as a mission and slightly broader than supporting the energy transition as a mission.

2.4 Evolution of domestic value chains

Investigating how the evolution of innovation systems supports industrial development is at the core of innovation system studies (Carlsson and Stankiewicz, 1991; Malerba, 1996). To explain the evolution of innovation systems, the innovation systems approach draws from the literature on technology and

industry life cycles. Work on technology life cycles has found that emerging technology development typically follows a particular pattern: in the early stages, the focus was on product innovations, while over time, the focus has instead shifted towards process innovation (Utterback and Abernathy, 1975). The industry life cycle literature tries to link this pattern of product and process innovations to the evolution of industrial structures (Abernathy and Utterback, 1978; Klepper, 1997). These studies found that the early stages of a new industry are characterised by the entry of new firms, while the selection of viable alternatives leads to firm exit and growth (Klepper, 1997).

Recent research on renewable energy technologies suggests that the length of different life cycle stages differs between technologies. For solar PV, for example, the focus of innovative activities shifted from product to process innovations, while for wind turbine technologies, the focus remained on product innovation (Huenteler et al., 2016). The patterns of such renewable energy technology lifecycles have also been linked to the emergence of spatial lifecycles. For example, Binz et al. (2017) found that spatial proximity in innovation processes was less relevant for solar PV through the shift in innovative activities, which allowed a global development trajectory (see also, Huenteler et al., 2016). These scholars found that the underlying reason for this development was the scope of modularisation of products and process steps, and hence specialisation and economies of scale (Binz et al., 2017).

Building upon the technology and industry life cycle literature, innovation system scholars suggest that the emergence of innovation systems follows a typical pattern (Bergek et al., 2008; Markard, 2020). Innovation system scholars apply a broader perspective to industrial development, suggesting that other structural elements, such as institutions and the dynamics created within innovation systems, besides technologies and industrial structures, influence technological progress and industrial development (Malerba, 1996). The formative phase of innovation systems is characterised by a variety of creation and experimentation with different technologies, whereas the focus shifts in the subsequent growth phase towards the scale-up and deployment of viable technologies (Bergek et al., 2008).

Over time, the research interest widened towards a better understanding of the structural development of production systems/ industries, referred to as longitudinal studies. These studies are based upon previous work on technology interaction. Reflections on technology interaction seek to investigate the dynamics in technology spillovers (Pistorius and Utterback, 1997; Sandén and Hillman, 2011). To conceptualise technology interaction within innovation systems, Sandén and Hillman (2011) introduce the concept of a value chain bundle. It suggests that any technology or sector can be understood as a combination of material, organisational, and institutional elements and that interaction can occur related to one or several factors. Potentialities of interaction abound, such as sharing common infrastructure or competition for institutional resources (Hillman, 2008; Sandén and Hillman, 2011). The value chain bundle concept has provided the theoretical starting point for recent research on value chains in sustainability transitions. For example, De Oliveira and Negro (2019) show how several value chains

formed around biogas technology in Brazil. More abstractly, Andersson et al. (2021) show the diversity of technological artefacts, organisational structures, and spatial distributions across various renewable energy technologies.

Other work on innovation systems has applied a sectoral perspective to study how value chains evolve around emerging technologies. These studies build upon insights from the sectoral systems approach. At its core, studies on sectoral systems argue that how new knowledge develops differs significantly between sectors and technologies, with implications for developing industrial structures (Malerba, 2002). Recent research on emerging technologies for sustainability transitions assumes that emerging technologies are typically based on multiple components (e.g., central and peripheral components). Hence, value chains typically cut across different sectors and established industries (Stephan et al., 2017). These studies seek to understand how innovation processes unfold as a combination of dynamics within and between different sectors. Empirical analyses have shown that different value chain sectors are involved in innovation processes related to different renewable energy technologies. The development of lithium-ion batteries, for example, has been based on the collaboration of upstream and downstream sectors, and for wind turbines, collaboration with end-users has been crucial (Malhotra et al., 2019; Stephan et al., 2017).

To conclude, existing innovation systems research provides valuable insight into the emergence and evolution of value chains. With the increasing global dynamics of sustainability transitions, value chains are typically distributed across several countries (Binz et al., 2017). Recent research suggests that domestic industries are linked to global dynamics (Hipp and Binz, 2020; Van der Loos et al., 2022). For example, countries can use foreign innovations, but domestic innovations can also spread globally, intentionally or not (Carlsson and Stankiewicz, 1991). Up to this point, however, we lack a systematic understanding of how countries are integrated into global value chains. This thesis attempts to fill part of this gap by investigating how domestic industrial activities are organised in global value chains, and the role of policy mixes therein.

2.5 Research outline

This thesis argues that combining insights from the reviewed research streams can reveal lessons on the role of innovation policies in industrial transformation. The purpose of this thesis is to analyse the interplay between policy mixes and industrial transformation processes directed towards net zero emission or other similar mission-oriented goals. While much progress has been made in studying the impact of policy mixes on the development and deployment of renewable energy technologies (Reichardt and Rogge, 2016) and the phase-out of existing technologies (Kivimaa and Kern, 2016;

Rogge and Johnstone, 2017), it remains rather unclear how policymakers can influence industrial transformation processes.

Fig. 1 illustrates the research framework of this thesis and specifies the links to the appended papers. This thesis analyses the innovation system supporting the transformation of established industry sectors. The innovation system provides an environment for actors, networks, and institutions to develop, scale up, and diffuse new technologies (Bergek et al., 2008; Carlsson and Stankiewicz, 1991).

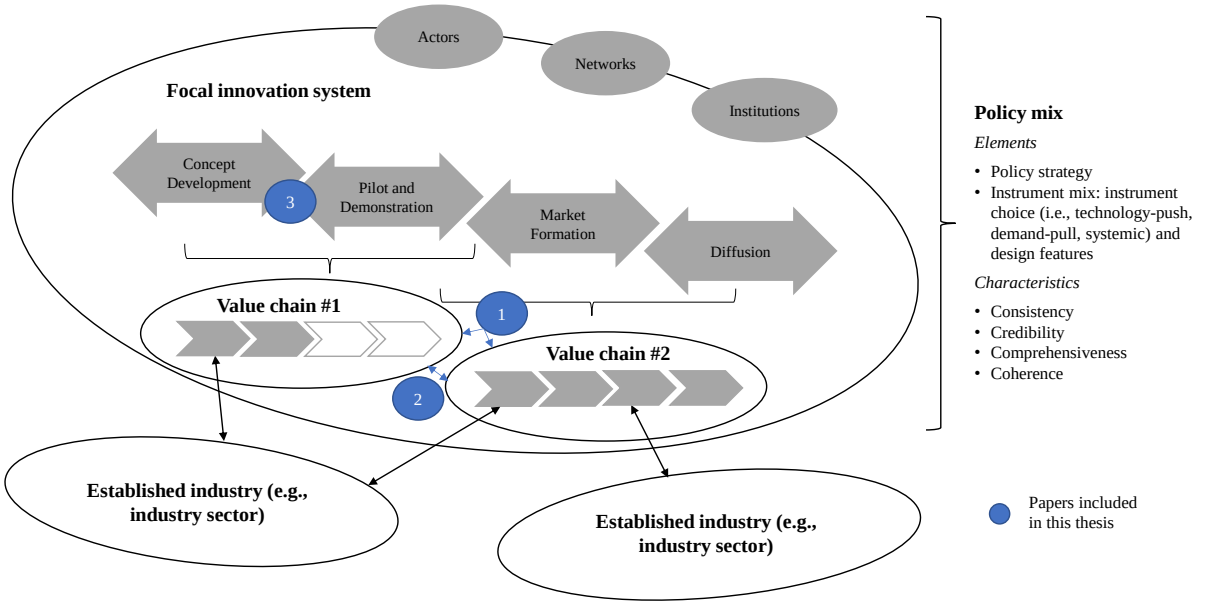

Figure 1: Links between research framework and papers included in this thesis.

Papers 1 and 2 focus on the impact of policy mixes on the evolution of domestic value chains associated with emerging technologies. Paper 1 takes a systemic perspective on domestic industrial development and aims to demonstrate the relevance of policy mix design and implementation for the emergence and shape of domestic value chains. While previous studies have highlighted the importance of policy mix design and characteristics for localising different value chain sectors (Matsuo and Schmidt, 2019; Reichardt and Rogge, 2016; Rogge and Dütschke, 2018; Rogge and Schleich, 2018), too little insight is provided into the policy effects on the evolution of value chains. However, previous studies have stressed that the formation of cross-sectoral dynamics is often associated with major challenges and suggest that policymakers must address innovation dynamics within and across sectors (e.g., Hipp and Binz, 2020; Malhotra et al., 2019; Stephan et al., 2017).

Paper 2 builds on the idea of Paper 1 and introduces a dynamic perspective on the evolution of policy mixes and the subsequent impact on the emergence and evolution of technologies and industrial structures. It aims to understand how policy mixes evolve in forming new industries and the subsequent

effects on technological and industrial development. Previous studies have demonstrated the importance of policy feedback in sustainability transition and called for a stronger consideration of policy processes to reflect real-world dynamics and complexities of sustainability transitions (e.g., Kern and Rogge, 2018). While studies on policy mixes for green industries typically devote attention to the design and characteristics of policy mixes (e.g., Matsuo and Schmidt, 2019; Reichardt and Rogge, 2016; Rogge and Schleich, 2018), much uncertainty still exists about the role of policy feedbacks on industrial transformation over time.

Paper 3 focuses on the impact of a transformative technology-push instrument on network formation. It aims to understand the innovation dynamics created among the incumbent industrial actors. While recent research suggests that policymakers can implement transformative innovation policies to direct transition processes, e.g., for reducing emissions in the established industry (for a recent review, see Haddad et al., 2022), little is known about their actual impact on the innovative behaviour of incumbents. This gap is particularly notable, given that past research on sustainability transitions has shown the reluctant behaviour of incumbents in such processes (cf., Köhler et al., 2019).

3 Research design

3.1 Case selection

This thesis work has been funded by the Swedish Energy Agency (The transition towards a bioeconomy: innovation policy instruments and their impacts) and Nordforsk (New Nordic Ways for Green Growth – NOWAGG). The thesis has contributed to the above projects with three case studies from the process industry, and the appended papers analyse different technologies and countries in the Nordic countries. The projects focus on the industrial transformation in Northern Europe. Still, the case studies for each paper have been selected and motivated by the research questions and purpose addressed in each paper. Table 2 presents an overview of the cases addressed in each paper. In the following, the rationales for case selection are discussed in more detail in relation to the specific aims of the individual papers.

Table 2: Overview of the selected research cases in the appended papers

Paper	Title	Purpose	Selected case study		
			Technological focus	Geographic scope	Period
1	Between national policy mixes and global innovation dynamics: a typology of value chains	Investigate how the design and characteristics of policy mixes influence the evolution and emergence of value chains in global sustainability transitions	Biofuels	Finland, Sweden	2003-2020
2	Fostering domestic green industry growth in the presence of policy feedback: the case of the Swedish Biofuels Industry	Investigate how policy feedback dynamics drive the development of a domestic policy mix relative to the growth of the technology and industrial structure	Biofuels	Sweden	2003-2020
3	Networks and technologies towards zero emissions in the industry: The case of Swedish R&D networks in policy-driven mission-oriented industrial transformations	Investigate the position of incumbent actors in relation to other value chain actors and examine what they invest in, how much, and the role of other actors.	Process industry (refining, etc.)	Sweden	2018-2022

Paper 1 investigates the impact of policy mix design and characteristics on the evolution of value chains in global sustainability transitions. To this end, a comparative case study analysis of biofuels in two countries with similar preconditions, namely Finland and Sweden, has been selected. The cases have been chosen for several reasons. The development of biofuels has been primarily driven by public policies (IEA, 2021a) and is considered an important pillar in the decarbonisation of the transport sector (IEA, 2021b). In addition, past studies have suggested that biofuels can have a wide variation in geographical distribution (Huenteler et al., 2016). Biofuel technologies can be adapted and chosen about local resource endowments, e.g., straw, forest, or food waste, which can facilitate industry localisation (Stafford et al., 2017). Finland and Sweden have been selected due to relatively comparable preconditions to induce domestic biofuel industries, with high forest resources, pre-existing oil and forest industries, and technological developers. Both countries have decided on goals to develop domestic biofuel industries and implemented instrument mixes to facilitate such development. The period has been limited to 2003 to 2020 since both countries have been mandated to implement biofuel policies under the EU biofuel policy frameworks, and considerable growth of biofuels occurred in both countries.

In Paper 2, the aim is to study how policy mixes are shaped and how this is affected by and affects the evolution of technologies and industrial structures. To this end, the case of biofuels has been selected for three reasons. First, biofuels are considered important to decarbonise the transport sector, particularly as they hold a high short-term potential to meet decarbonisation targets (IRENA, 2016). Second, past studies have shown that the development of biofuels has largely been driven by public policies (Hellsmark and Söderholm, 2017; Su et al., 2015). Third, past studies have revealed variations in the geographical distribution of value chains in the biofuel industry, ranging from domestic to global configurations (Gregg et al., 2017; Huenteler et al., 2016). Against this backdrop, this paper focuses on biofuels in Sweden as a research case. Sweden has become one of the frontrunners in developing biofuel technologies and the growth of importer structures. Past studies have shown that several different production technologies have been developed and, to some extent, deployed in Sweden (e.g., gasification-based gasoline, FT-diesel, bio-based oil diesel) (Lönnqvist et al., 2021). The period of 2003 and 2020 has been chosen since a policy mix has been in place during this period and notable industry growth occurred.

Paper 3 seeks to investigate the effects of the Swedish innovation policy instrument *Industriklivet* on experimentation with emerging technologies, such as hydrogen and carbon capture, across the main emitters in the Swedish industry. The research case has been selected for two main reasons. First, Sweden has set the ambition to attain net zero emissions by 2045. As part of the policy mix to achieve this target, a collaborative RD&D programme has been implemented, dedicated to network formation and technological innovation. Second, the process industry is a significant sector in Sweden and

accounts for most of the Swedish emissions from industry. In total, there are 18 companies responsible for 95% of all emissions in the country's process industry.

3.2 Methods

Given the exploratory nature of this thesis, a qualitative research strategy has been selected. It has been argued that qualitative research generates new empirical and theoretical insights (Eisenhardt, 1989). The appended papers draw on different methods and data to address the research questions, as outlined in Table 3. In the following, the strategies for data collection and analysis are summarised, and a detailed description can be found in the appended papers.

Table 3: Overview of the methods and data used in the individual papers

Paper	Title	Method	Data
1	Between national policy mixes and global innovation dynamics: a typology of value chains	Mixed Methods	Interview data, secondary data, observations at industry conferences, a stakeholder workshop
2	Fostering domestic green industry growth in the presence of policy feedback: the case of the Swedish biofuels industry	Mixed Methods	Interview data, secondary data, newspaper articles
3	Networks and technologies towards zero emissions in the industry: The case of Swedish R&D networks in policy-driven industrial transformations	Social network analysis	Dataset on Swedish emissions inventory, collaborative research projects under the 'Industriklivet' program

Paper 1 seeks to uncover how policy mixes' design and characteristics could influence value chain development. Following the strategies outlined by Eisenhardt (2016, 1989) and Eisenhardt and Graebner (2007), the analysis was conducted in three main steps. First, rich narratives were constructed to develop an in-depth understanding of the historical development of biofuels in both countries, each between 20 and 30 pages. These described how the industrial activities developed over time and the role of the respective policy mixes therein. The narratives drew on data from semi-structured interviews with policy, industry, and research representatives, secondary materials such as policy documents, and observations at industry workshops. The authors used summary tables to derive the design and characteristics of policy mixes (see also Kern et al., 2017; Rogge and Reichardt, 2016). Second, to gain deeper insights into the impact of policy mixes on the formation of value chains within the respective innovation systems and reduce the length of the narratives, we searched for general patterns of

innovation dynamics. This was facilitated by longitudinal mappings that linked the development of the policy mixes to the main value chain activities. To discuss and validate the findings, a stakeholder workshop was conducted to get feedback from research, industry, and policy representatives. Third, cross-case comparisons were conducted through pattern-matching to arrive at a more theoretical understanding of the relationships between policy mixes and value chains. As a result, five distinct types of value chains can be distinguished for which policy plays different roles; each labelled after the main activities of the domestic lead actor.

To analyse how the dynamic interaction between policy mixes and technologies and industrial structures affect industry formation, Paper 2 analyses the main mechanisms and patterns driving the evolution of the Swedish biofuel industry. The analysis was conducted in three main steps. First, to familiarise with the evolution and emergence of the Swedish biofuel industry, a mapping of the main actors, plants, policy mix elements etc., was conducted and summarised in a narrative description. A combination of interview, secondary, and bibliometric data on scientific publications was used. Second, a content analysis was conducted using newspaper articles to gain a deeper understanding of the feedback mechanisms linking policy mixes, technologies, and industrial structures. In addition, the data was further supplemented by analysing publicly funded research projects. The identified feedback was added to the narrative developed in the first step. Third, building upon the empirical analysis, the main feedback between the policy mix and the respective technologies and industrial structures was traced to generate a more abstract understanding of the emerging process and its effects on industry shape.

Paper 3 conducts a social network analysis of the collaborative R&D network created by Industriklivet in Sweden to investigate the effect of the innovation policy instrument Industriklivet on the transition of the main Swedish emitters. More specifically, the paper analyses the role and activities of the main Swedish emitters in the R&D network. To this end, the paper proceeds in two steps. First, this paper draws on information about emissions from facilities and organisations included in the EU-ETS to identify the main Swedish emitters. The dataset was retrieved from the Swedish Environmental Protection Agency. Second, to determine the effects of Industriklivet, the paper analyses the R&D projects funded within the program. The data of the R&D projects were retrieved from the Swedish Energy Agency. The projects were inductively categorised into different groups of technological orientations, and each group was subsequently categorised according to technological foci. We used a social network approach to study the role of the main emitters and how they interact with each other. Social network analysis offers tools for discovering structure patterns, making it an appropriate approach for analysing the transition dynamics created among the main emitters.

4 Results

The following section summarises the main results and key contributions from the three appended papers.

4.1 Paper 1

Paper 1 focuses on the impact of policy coordination on the emergence and evolution of domestic value chains. While innovation system scholars have stressed the global distribution of value chains (Hipp and Binz, 2020; Van der Loos et al., 2022), much uncertainty still exists concerning the influence of policy mix design and implementation on the development of domestic industries in the context of global value chains (see, Matsuo and Schmidt, 2019, for a notable exemption). To address this research gap, this paper investigates how policy design and characteristics affect the evolution of value chains.

The findings show similarities and differences in how the respective biofuel policy mixes were designed and implemented in Finland and Sweden between 2003 and 2020. Table 4 presents an overview of the main elements, processes, and characteristics of the respective policy mixes. While the early design of the Finnish policy mix has maintained relatively stable of the studied time period, including feedback from stakeholders, the policy mix in Sweden has instead emerged over time through the additions and tweaking of instruments.

Table 4: Comparison of the main elements, processes, and characteristics of the biofuel policy mixes in Finland and Sweden (2003-2020)

PM	Finland	Sweden
Elements	Blending obligation, tax relief for biofuels, collaborative R&D programme, investment subsidies	Taxation strategy on 1–2-year basis, since 2018 reduction obligation for low-blends, collaborative R&D programme, investment subsidies
Processes	Policy designed and adapted with feedback from stakeholders	Policy designed by policymakers, stakeholder feedback, received, yet not necessarily followed through
Characteristics	High consistency, credibility, and coherence, less comprehensive	Lower credibility, consistency of demand-pull instrument, coherence, higher comprehensiveness

Regarding the impact of the policy mixes on the formation of innovative activities along biofuel technology value chains between 2003 and 2020, the findings show substantial differences between both countries. In Finland, the policy mix mainly provided incentives for large companies from the domestic oil and forest industries to develop and scale up the first production capacity in the country domestically and additional capacities worldwide. Conversely, the Swedish policy mix incentivised

different actors, such as specialised technology developers, importers of biofuels, and adopters of foreign technologies. However, few domestic technology projects could scale up thus far.

Nevertheless, despite the observed differences concerning the policy mixes and resulting value chains, we find similar patterns – types - of value chains emerging in both countries. Based on the empirical findings, the paper develops a typology of value chains. Five distinct types of value chains are derived, summarised in Table A1 in the appendix. Each value chain is defined on the material, organisational, and spatial dimensions, and labelled after the main characteristics of the domestic lead actor. The typology also describes, compares, and explains for each type how the design and implementation of policy mixes in Finland and Sweden have affected their emergence and evolution, having regard for other explanatory factors.

By explicitly discussing how the design of national policy mixes is linked to the emergence and evolution of value chains, the paper contributes to the nascent discussion on domestic industrial development within the policy mix community (e.g., Matsuo and Schmidt, 2019; Reichardt and Rogge, 2016; Rogge and Dütschke, 2018; Rogge and Schleich, 2018). Whereas existing studies typically analyse the impact of policy mixes on the localisation of different sectors, this paper contributes with a better understanding of the potential outcomes.

The paper also advances the discussion about the emergence of domestic value chains in global industry dynamics (Hipp and Binz, 2020; Stephan et al., 2017; Van der Loos et al., 2022) by providing systematic knowledge of the patterns (types) of value chains emerging in global sustainability transitions.

4.2 Paper 2

As an extension of Paper 1, Paper 2 focuses on the impact of policy mixes on the industrial development associated with emerging technologies in the presence of policy feedback. While the role of policies and politics for industrial development associated with emerging technologies has been a continuing concern in the innovation systems literature (e.g., Jacobsson and Lauber, 2006; Nelson, 1995), previous work provide provides limited insight into the process mechanisms underpinning the co-evolution of policy, technologies, and industrial structures. To address this research gap, Paper 2 investigates the evolution of the Swedish biofuel policy mix over the period 2003-2020 and the subsequent effects on the technologies and industrial structures emerging in Sweden.

To this end, this paper combines the innovation systems approach with insights from the literature on policy feedback. Specifically, it builds upon recent studies on policy feedback in sustainability transitions; these studies seek to explain the mechanisms linking policy mixes and sociotechnical change (Edmondson et al., 2019). The paper builds on a historical case analysis of the Swedish biofuel industry.

The analysis shows how the Swedish policy mix has changed over time. In 2003, in response to the EU Biofuels Directive, the Swedish government tweaked the carbon dioxide tax already in place to create a commercial market for biofuels. In parallel, the government developed a strategy, with input from pre-existing actor networks (e.g., research networks, specialised technology suppliers), to scale up small-scale technologies to develop a domestic wood-based biofuel industry based on the pre-existing forest industry. Over time, the policymakers have adjusted the policy mix in response to industrial progress, e.g., to enlarge the market size and increase R&D funding. Additionally, to comply with EU regulations, policymakers had to amend the design of the taxation strategy and later, replace it with a biofuel reduction obligation, as EU regulations regarding state aid changed. National climate and energy policies also repeatedly affected the biofuel policy mix.

The findings show that the evolution of the Swedish biofuel policy mix greatly affected the technologies and industrial structures emerging in Sweden. The policy mix has induced a wide range of actors to engage in the import of biofuels, and it also promoted the development of different technologies for advanced biofuel products (e.g., DME for adapted trucks) by various actor networks. Additionally, several smaller actors could install production capacities for different drop-in biofuels based on foreign technologies (e.g., agricultural cooperative Lantmännen, chemical company Perstorp) and one joint venture based on proprietary technology (Sunpine). With the increasing adaptation of the Swedish policy mix over time, industrial actors perceived the policy mix as less credible and inconsistent, thus not facilitating large-scale investment decisions. While this ended earlier technology projects for advanced biofuel products, new small-scale projects emerged with simplified product properties (i.e., drop-in biofuels).

While the empirical analysis is based on the Swedish case, Paper 2 also identifies and conceptualises a generic process mechanism that discusses how policy changes over time and how this subsequently affects the evolution of the domestic industry. The paper argues that repeated patterns of policy feedback produce a particular type of policy mix adapted to solving the feedback of the "loudest voices" within a given context, besides regulatory compliance issues and broader policy changes. This, in turn, will impact how technologies and industrial structures unfold in the emergence of new domestic industries. Figure 2 illustrates how the interplay between policy mixes and technology and industrial structures affects the emergence of new domestic industries over time.

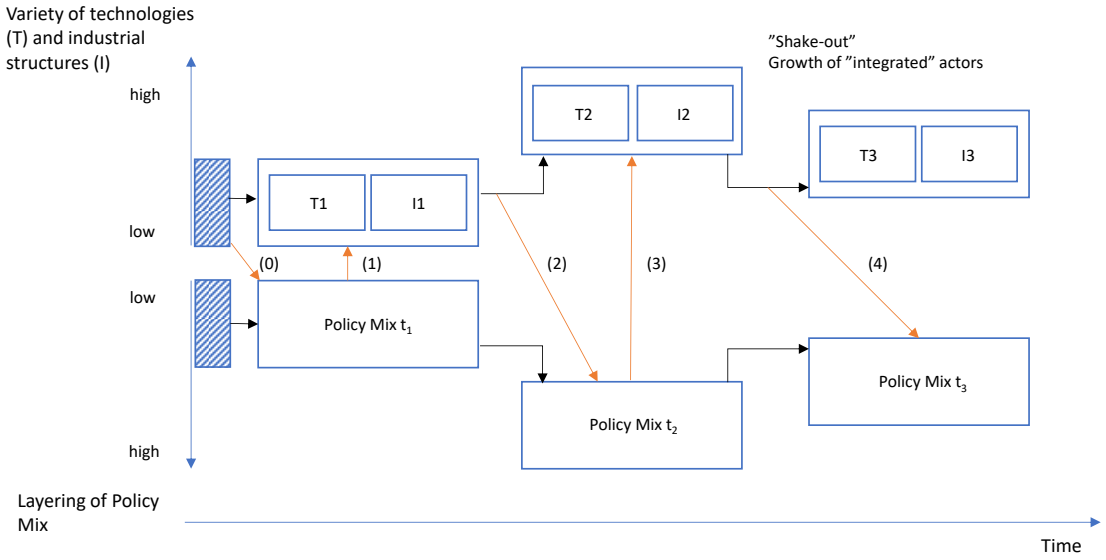

Figure 2: Stylised model illustrating the role of policy feedback in the coevolutionary process between a policy mix, technologies (T_n) and industrial structures (I_n). The orange arrows point to the main policy feedback dynamics over time. The black arrows indicate the respective development of policy and industrial processes.

Our findings suggest that the process consists of several stages.

- (0) Pre-existing technologies and industrial structures influence the design and implementation of the policy mix.
- (1) effects created by policy mix influence which technologies and industrial structures move forward.
- (2) Feedback related to technologies and industrial structures may lead to frequent policy mix changes.
- (3) Policy mix adjustments may create uncertainties and, in turn, affect evolutionary dynamics and lead to a "shake out" of technologies and industrial structures. At the same time, it provides opportunities for intense learning processes and dominance of actors or actor networks ("integrated actors").
- (4) Policy feedback created by integrated actors shaping the evolution of the policy mix in their favour. Other actors either can adapt and find niches or go extinct.

The paper contributes to innovation system studies focusing on industrial development by explaining the process through which policy mixes evolve in innovation systems and how this subsequently influences the creation and selection of technologies and industrial structures. In doing so, this research addresses calls of previous innovation system studies to draw on policy theories to better understand how policy processes influence innovation and transition dynamics (e.g., Flanagan et al., 2011; Kern and Rogge, 2018).

By integrating policy feedback theory with an evolutionary perspective to innovation systems, the paper also adds to the understanding of the evolutionary dynamics created by policy feedback in sustainability transitions that have not yet been explored in-depth in previous literature relating policy feedback theory to sociotechnical change (Edmondson et al., 2020, 2019).

4.3 Paper 3

As an extension of papers 1 and 2, paper 3 expands the focus from biofuels to a broader range of emerging technologies, including hydrogen and electrification and carbon capture and storage. While a growing number of countries have implemented transformative innovation policies to achieve net-zero emissions in industry, the actual effects of such policies on transition processes in the industry remain largely unexplored. This research gap is particularly surprising, given that previous research has emphasised that incumbent actors have often been reluctant to sustainability transitions (e.g., Hellsmark and Hansen, 2020; Stirling, 2019). To address this research gap, this paper investigates the effects of the Swedish innovation policy instrument Industriklivet on experimentation with emerging technologies, such as hydrogen and carbon capture, across the main emitters in the Swedish industry.

The paper uses the mission-oriented innovation systems approach to structure the empirical analysis. It develops a database that links the main Swedish carbon dioxide emitters to the research projects funded under the Industriklivet programme. The empirical analysis shows that 80% of the Swedish emissions included in EU-ETS (13Mtons CO_2 emissions) are linked to 20 companies from the cement, chemicals, heat, power, iron, steel, other metals, and refinery sectors in the following referred to as main emitters. Several of these companies have adopted zero-emissions targets and started efforts to reduce emissions, such as increasing energy efficiency, recycling, and using biomass as a substitute for fossil fuels. Between 2018 and mid-2022, 17 of the 20 main emitters were part of the Industriklivet programme.

Figure 3 illustrates the technological foci pursued by the main emitters and other actors within the R&D network. 16 of the main emitters collaborate with other networks to realise different renewable energy and low-carbon technologies, while one main emitter is not involved in any projects. Comparing the networks of actors in different industries reveals substantial differences. While the iron and steel industry encompasses the lowest technology variation, highest network activity, and variation of actors, including main emitters, other industry actors, public research actors, and one new entrant, other industries have significantly higher variation with regard to technologies, fewer actors and network activity (chemicals and refinery, cement and minerals, heat, and power). The findings also show that the main emitters have different positions in the R&D network (indicated by number of indirect contacts). Some actors (e.g., the chemical company Cementa) possess a high number of indirected

contacts, indicating relative ease in reaching all other actors in the network (Kogut, 2000; Walker et al., 1997).

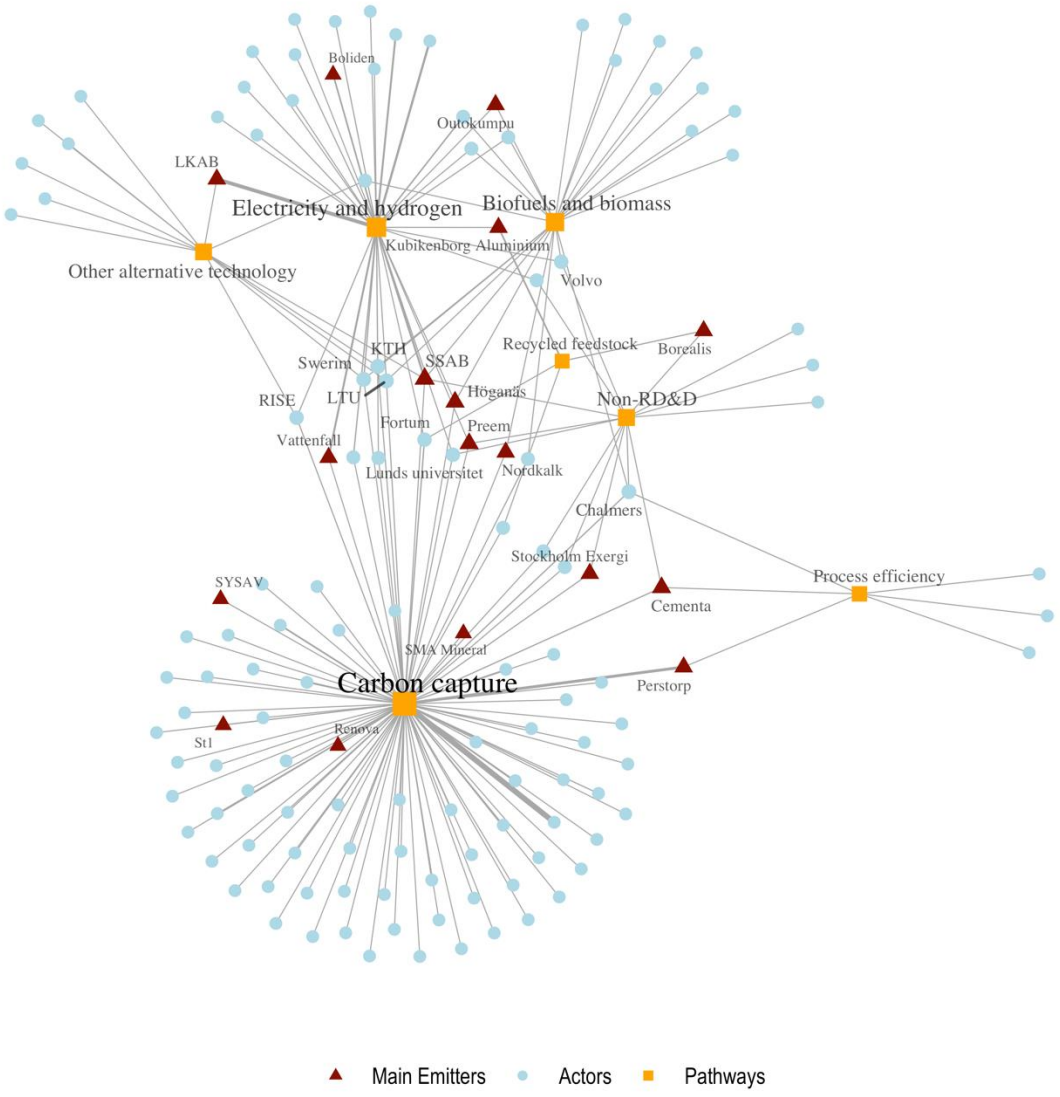

Figure 3: Technological foci pursued in Industriklivet by main emitters and other actors in the R&D network

The analysis of the Swedish R&D programme Industriklivet indicates that transformative policy initiatives are effective in promoting innovation activities, which enable the transition to net-zero emissions. However, the findings also suggest that incumbents influence the directionality of innovation activities. We found that the incumbents influence network development and technological selection mechanisms. Collectively, these findings emphasise the importance for policymakers to address the variety-selection trade-off and tackle differences related to the transition progress of different target industries.

This paper provides empirical support to the discussion that transformative innovation policies can effectively promote innovation and transition dynamics (Andersson and Hellsmark, 2022; Janssen et al., 2022; Mazzucato, 2018; Wanzenböck et al., 2020).

The paper contributes to the emerging literature on mission-oriented innovation system studies by demonstrating that the mission-oriented innovation systems approach can help study transition processes.

5 Discussion

5.1 Discussion of the findings

The purpose of this thesis is to analyse the interplay between policy mixes and industrial transformation processes directed towards net zero emission or other similar mission-oriented goals. To do so, this thesis has presented three views of the processes between policy mixes and industrial transformation in three appended papers. Each paper deals with different aspects of the impact of domestic policy mixes on industrial transition processes. While Section 4 summarises each paper's findings and key contributions, this section discusses this thesis's overarching findings and contributions.

This thesis found that differences in the design features and characteristics of biofuel policy mixes in Finland and Sweden (RQ1) have led to different incentive structures, which in turn have encouraged different industrial activities (RQ2). The analysis of the Swedish biofuel case has shown how the Swedish policy mix has been established based on feedback from different industrial actors (e.g., technology suppliers and research actors). The analysis has also shown how the policy mix has developed over time based on concerns and pressure from the industry (RQ3). The Swedish policy mix helped stimulate technological development, investment, and market deployment. The findings have also revealed that the feedback from powerful industrial actors to policy has created a destructive lock-in for smaller technology suppliers, which led to the subsequent failure of several attempts to commercialise technology projects (RQ4).

This thesis also shows how the Swedish policy instrument Industriklivet has stimulated experimentation across the Swedish main industrial emitters with a range of low-carbon and renewable energy technologies (RQ5).

Furthermore, the thesis found and conceptualised several mechanisms that help articulate the underlying processes by which transformative innovation policies influence industrial transformation. More specifically, the findings describe and explain how the design and the characteristics of a policy mix influence the emergence and shapes of domestic value chains associated with emerging technologies. The research of Paper 1 resulted in a typology which explains how differences in policy mix designs and characteristics lead to different value chains against the backdrop of exogenous factors. Additionally, Paper 2 found that policy feedbacks limit the propensity of policymakers to promote diverse value chains over time.

The thesis shows how transformative innovation policies – consisting of strategic goals, roadmaps/ missions, and a mix of instruments – can potentially promote industrial development processes. Overall, these findings provide empirical support for the arguments of existing studies (cf. (Löfgren and Rootzén, 2021; Nilsson et al., 2021)) on the industrial transformation that comprehensive public policies are vital for breaking down incumbent infrastructures and production systems, to create

technological and organisational variation as well as to increase competition. The findings add to this argument by showing how the design, characteristics and implementation of policy mixes are vital for promoting specific industrial structures, such as domestic value chains. At the same time, however, the findings also point towards risks of locking in policy mixes and risks of policies strongly influenced by dominant actors.

This thesis also adds to this argument by providing novel insight into the underlying processes by which policies influence the industrial transformation. The case of the Swedish industry confirms that policymakers can incentivise existing industrial actors to participate in R&D networks. Knowledge networks constitute development blocks for technological innovation and subsequent diffusion of viable alternatives throughout the industry (Carlsson and Stankiewicz, 1991). The findings also show that policies effectively promote the scale-up and industrialisation of emerging technologies. However, the findings suggest that the preconditions for policymakers to enable industrial transformation processes become more complex as new technologies mature. The biofuel cases highlight that policymakers can promote diverse, innovative activities and the entry of different types of actors. In contrast, increasing differences in the required political support across actors and technologies and policy feedback limit the abilities of policymakers to promote and scale up diverse pathways over time.

Furthermore, these findings provide potentially essential insights into the emerging debate about the opportunities and limitations for policymakers to maintain significant parts of value chains within the home country in global industry dynamics (Hermwille et al., 2022; Hipp and Binz, 2020; Van der Loos et al., 2022). Previous research has highlighted that the established industry is characterised by large incumbents (Wesseling et al., 2017). The biofuel cases indicate that large incumbent actors seek to pursue large process scales and tend to depend on global market and policy developments. However, the biofuel cases have also illustrated that global markets are highly volatile. Although industrial products, such as green steel, are rather supported than induced by policies, negotiations for global markets for the established industry have only been launched, such as for green steel and aluminium (United States and European Union, 2021). Taking into account all aspects of the analysis, this thesis argues that policymakers need to be aware of the risks linked to the scale-up of industrial transition processes and the difficulties of keeping large shares of multinational incumbent-centred value chains. Building upon the biofuel case, promoting smaller actors focused on domestic markets in parallel would keep the widest array of options open.

Contrary to expectations of mature markets dominated by incumbent interest, we still find a few new entrants taking different value chain positions (e.g., H2Green Steel as a steel producer, Nordic Green Fuel as a biofuel producer, specialised technology companies including Sekab and Chemrec, and joint ventures such as Sunpine). According to the empirical evidence, these actors tend to localise large shares of value chains in the home country (e.g., technology development or production), which is particularly

important for smaller countries, such as Finland and Sweden. However, at this point, not all aspects of the role of new entrants in industrial transformation processes are sufficiently understood.

Moreover, previous research has stressed that industrial transformation can occur through different pathways, with the emergence of new technologies as one potential solution (Bauer et al., 2022; Geels et al., 2016; Nilsson et al., 2021). While this thesis contributes to the understanding of industrial development associated with emerging technologies (e.g., biofuels), more research is needed to establish the emergence and co-evolution of alternative pathways.

More broadly, these findings contribute to the literature on transformative innovation policies by providing insights into the underlying processes by which transformative innovation policies influence innovation and transition processes. Existing research has emphasised that promoting and maintaining a plurality of pathways when implementing directed policies helps deal with the uncertainties and complexities inherent to innovation processes (Stirling, 2008). Recent research has shown that the solution space can consist of a wide range of value chains (Andersson et al., 2021) and has argued that the feasibility of different pathways will be affected by politics (Bauer et al., 2022). This thesis contributes to this literature by demonstrating how policy design and policy feedback interact and shape industrial transitions. The cases confirm that policy feedback and evolutionary selection processes limit the number of feasible pathways. Based on the Swedish biofuel case, this thesis also found that novel technologies can gain a competitive advantage in selection environments (e.g., HVO outcompeting biodiesel). Still, further research is needed to examine the resulting dynamics in other contexts.

By empirically investigating the R&D network created in the policy-driven transformation of the Swedish industry, the thesis also contributes to understanding the innovation system dynamics created by transformative innovation policies (Andersson and Hellsmark, 2022; Wanzenböck et al., 2020; Wesseling and Meijerhof, n.d.). The thesis contributes to a better understanding of the R&D networks created by collaborative R&D programmes. Additionally, the analysis demonstrates that the approach of mission-oriented innovation systems represents a valuable tool to conceptualise and studying directed transition processes (Hekkert et al., 2020; Wesseling and Meijerhof, n.d.). In particular, the thesis suggests that a social network approach to investigating the innovation system and transition dynamics can help study and evaluate the impact of transformative innovation policies. Continuous monitoring of the effects of such policies is crucial in an era of stringent climate policy goals (cf. Haddad et al., 2022).

Furthermore, the findings also advance the discussion about the development of domestic industries in global value chains (Andersson et al., 2021; De Oliveira and Negro, 2019; Hipp and Binz, 2020; Stephan et al., 2017; Van der Loos et al., 2022). By connecting different approaches to value chain studies within the innovation systems literature, this thesis contributes novel insights into the processes by which domestic industries emerge in global sustainability transitions. More specifically, the thesis

contributes with a typology of value chains. This typology describes and explains the emergence of potential industrial structures and a process model that describes the dynamic co-evolution of value chains in domestic innovation systems.

Finally, the findings of this thesis also have several implications for policymakers who wish to stimulate and accelerate the industrial transformation towards net zero emissions. First, the findings highlight that policymakers need to acknowledge that typically different actors and actor networks enter industrial transformation processes and that these actors often depend on different forms of political support. This implies that policymakers need to develop a profound understanding of the domestic actors, their potential and actual strategies, and the opportunities for new entrants before designing roadmaps and missions.

Second, the findings highlight that policymakers should use the gained knowledge in the domestic industrial setting to develop realistic strategies and implement supporting policy mixes. The cases illustrate that different actors depend on different forms of policy design and sequencing to develop and deploy industrial activities.

Third, policymakers should also be aware of actor-inherent differences to participate in policy processes. According to the empirical evidence, actors differ in their abilities to mobilise and participate in policy processes and shape the evolution of policy mixes. Through stakeholder workshops or participatory policy processes, policymakers can try to facilitate the integration of less political actors.

5.2 Limitations and avenues for further research

The present thesis extends current knowledge of the impact of policy mixes on industrial transformation processes. Despite its exploratory nature, this thesis offers some insights into the possibilities and limitations for national policymakers to influence and accelerate the transformation of the established industry towards net zero emissions. The thesis has provided novel empirical and theoretical insights into the processes describing and explaining the impact by conducting three empirical case studies. Still, the findings are subject to at least two limitations, which provide promising avenues for further research.

First, the papers differ in their conceptual foci, from taking a technology perspective (Papers 1 and 2) to focusing on a mission (Paper 3). While the first two papers have dealt with the emergence of technologies over the life cycle (e.g., from formative to deployment and growth phase), the third paper has focused on network formation in the early-stage innovation dynamics. However, at this point, a life cycle perspective is lacking. Further research is needed to investigate the innovation and transition dynamics over an extended period.

Second, the thesis is based on an explorative case study approach. While all papers draw on qualitative and quantitative data, the papers rely heavily on qualitative research approaches to describe and explain the processes linking the impact of transformative innovation policies on industrial development. The research presented in this thesis has laid the groundwork for a better understanding of the processes and industrial outcomes, particularly through developing a typology and a process model. We hope that future research can build on these findings to identify, elaborate, and test basic contingencies.

6 Conclusions

Accelerating the transition of the established industry towards net-zero emissions is one key factor for national policymakers to achieve stringent national climate goals. The purpose of this thesis is to analyse the interplay between policy mixes and industrial transformation processes directed towards net zero emission or other similar mission-oriented goals. To do so, this thesis builds upon and combines insights from three appended papers. Each paper presents a historical case study analysis investigating how transformative innovation policy mixes have affected the emergence of biofuel industries and the transition of the established industry in Northern Europe.

The findings of this thesis have shown that the differences in the design and characteristics of biofuel policy mixes have led to different value chain development in Finland and Sweden. The findings have also demonstrated that policy feedback has limited policymakers' possibilities to promote the development and scale-up of varied technologies and industrial structures in emerging industries. Furthermore, the findings have shown that the Swedish innovation policy instrument Industriklivet has been effective in promoting experimentation with different low-carbon and renewable energy technologies among the main Swedish emitters.

While the findings provide empirical evidence that transformative innovation policies are effective in promoting industrial transformation toward net zero emissions, they also highlight that increasing differences in policy effects and policy feedback limit the abilities of policymakers to promote the scale-up of different pathways in parallel and maintain large shares of value chains within the home country.

Appendix

Table A1: Comparison of the impacts of the Finnish and Swedish Policy Mix on the evolution of different value chain types. The types are associated with typical patterns of material, organisational, and spatial configurations of value chains and are labelled after the main activities of the domestic lead actor.

		Policy mix Finland	**Policy mix Sweden**
	Main elements	Blending obligation, collaborative R&D programs and operation of PDPs, grants for domestic large-scale technology developments, R&D programs flexible in terms of technology, and specified to industry development.	Tax exemptions (2000-2018), CO_2 reduction obligation (2018-2030), RD&D grants for specific technologies, grants for large-scale technology developments, operation of PDPs
	Process	Orientation towards expert-driven decision-making, formal parties have been central actors. Industry systematically engaged in all phases of the policy-making process.	Integration of stakeholder perspective in preparatory work in investigations and discussions, however, less in preparation of legislation. Frequent adaptation of policies, preferences for incremental changes, limited learning effects
	Characteristics	Systemic design of policy mix, few adjustments over time, long-term and stable, a strong focus of policy mix (comprehensiveness) on academia and industry, fewer incentives for demand-side actors.	Layering of policy mix elements and frequent adjustments and attempts to change demand-pull instrument, low credibility and consistency, the gap between RD&D and commercial market
Type	**Main characteristics of value chain**	**Main policy mix impacts on industrial value chain types in Finland**	**Main policy mix impacts on industrial value chain types in Sweden**
1a Globally oriented innovator-producers	Drive by large corporations, in collaboration with research and value chain partners. Large-scale technology concepts are integrated into existing infrastructures (e.g., refinery concepts, pulp mills) and less complex products (e.g., drop-in biofuels). R&D work and first plants located within the home country, additional projects distributed globally	Technology development of HVO and the use of primarily palm oil created a good fit for the refinery infrastructure and was stimulated by EU targets. The cost of implementing the technology was relatively low for being an advanced fuel, and the quota system created a stable and protected market early in the EU and Finland. R&D and systemic instruments played a limited role.	Technology development of HVO using crude tall oil was stimulated by EU and national targets. Investment security was created through quota systems on other markets and not through the unstable exemptions to CO_2 tax. The reduction quota created conditions for experimenting with new types of bio-oil. R&D and systemic instruments played a limited role in the early investment but were more important for the expansion of new types of resources.

1b Domestically oriented innovator-producers	Driven by smaller firms, in collaboration with research and value chain partners. Technology concepts tailored to existing infrastructures (e.g., refinery concepts, pulp mills), low complex products (e.g., drop-in biofuels). R&D work and production plants are located within the home country.	Technology development has been geared towards utilising existing resource bases. R&D and systemic instruments have been key for inducing experiments in, e.g., gasification, but these have so far failed to become competitive in relation to the existing quota system. Instead, HVO production based on crude tall oil has been developed and supported by existing market-based instruments.	Limited effect of policy mix on the pulp and paper actors, which have not participated in major experiments. R&D and investment support have enabled one actor from the district heating sector to experiment with gasification. Still, exemption from CO_2 tax has not allowed investment in commercial scale plants. With the introduction of the reduction quota, a renewed interest in HVO from crude tall oil.
2 Technology developers	Driven by smaller firms, collaboration with research actors and wider networks with industry and policy. Variety of technology concepts and products, often with high-potential, complex products (e.g., adjustments of vehicle and tank infrastructure required)	Large technology suppliers have been able to benefit from RD&D support. National policy mix and, in particular, market instrument has not permitted scale-up within the country. Instead, market incentives introduced in other countries allowed for subsequent technology scale-up.	Significant RD&D support has been important. Lack of interest and participation of customers, in combination with weak incentives for capital-intensive investment with long pay-back times, have not enabled a scale-up of innovative solutions. Introduction of the reduction quota has spurred a new wave of technology suppliers focusing on the production of bio-oils and seeking collaboration with Type 1a actors.
3 Public research actors	Driven by public research actors. Development of generic knowledge and technology concepts. Projects located within the home country.	RD&D support important, while systemic instruments helped build a strong industry consortium, resulting in two industry alliances taking up the development. Biofuels quota, later supplemented by double counting of advanced biofuels, is not a strong enough market mechanism for firms to invest in technology on commercial scale.	Substantial RD&D support has enabled the takeover of private demonstration plants. Operation as permanent test centres allowed for experimentation and testing with technologies supported by various technology push instruments.
4 Producers	Driven by different domestic actors, integration into existing infrastructures. Technology developments abroad.	Introduction of the biofuels quota did not provide a market for biofuel projects of small actors that could not compete on price. Larger projects were halted or hampered due to a lack of technology subsidies for imported technologies. Introduction of separate quotas with high stringency induced actors to invest in more progressive technologies based on company financial resources or private venture capital. Adoption of technologies has been oriented towards the use of existing infrastructure.	Exemptions from CO_2 taxation provided strong incentives for several actors to install low-cost biofuel technologies. Change of demand-pull instrument and introduction of reduction quota provided strong inducement mechanism for lowest cost progressive technologies, investment subsidies for large-scale projects enabled building of several projects. Changes in EU feedstock regulation put mature projects under pressure, which in turn caused actors to resume R&D efforts to broaden the feedstock bases.
5 Importers of renewable energy	Driven by a wide range of actors, established collaborations with global producers.	Biofuels quota provided bounded market for lowest cost biofuels. Domestic oil refiners engaged in biofuel production (Type 1a and 4), imports and exports based on market prices.	Design of the taxation system offered profit margins, provided a large absolute market size for fast uptake of biofuels, and induced actors to build up huge importer structures. The implementation of reduction obligation induced a shift towards biofuels with highest GHG-reduction potential at lowest cost; however, tax exemptions for full blends still provide strong inducement mechanisms for importers.

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Appended papers

Paper 1

Between national policy mixes and global innovation dynamics: a typology of value chains

Barbara Hedeler[1], Jakob Donner-Amnell[2], Hans Hellsmark[1], Patrik Söderholm[3]

[1]Chalmers University of Technology, Department of Technology Management and Economy, Gothenburg, Sweden

[2]University of Eastern Finland, Department of Geographical and Historical Studies, Faculty of Social Sciences and Business Studies, Finland.

[3]Luleå Technical University, Department of Business Administration, Technology and Social Sciences, Division of Economics, Sweden.

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Paper 2

Fostering Domestic Green Industry Growth in the Presence of Policy Feedback: the Case of the Swedish Biofuels Industry

Barbara Hedeler[1], Hans Hellsmark[1], Patrik Söderholm[2]

[1]Chalmers University of Technology, Department of Technology Management and Economy, Gothenburg, Sweden

[2]Luleå University of Technology, Department of Business Administration, Technology and Social Sciences, Luleå, Sweden

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Paper 3

Networks and technologies towards zero emissions in the industry: the case of Swedish R&D networks in policy-driven mission-oriented industrial transformations

Barbara Hedeler[1], Johnn Andersson[2], Hans Hellsmark[1]

[1]Chalmers University of Technology, Department of Technology Management and Economy, Gothenburg, Sweden

[2]Luleå University of Technology, Department of Social Sciences, Technology and Arts, Luleå, Sweden

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