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Takeoff

Analysing Pathways for Electric Innovation Facilitation and Regime Destabilisation in the Swedish Aviation Industry

Kajsa Wimmerström

Supervisors

Sofie Sandin

Carl Dalhammar

Backa Fredrik Brandt

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The difficulty lies, not in the new ideas,
but in escaping from the old ones.

John Maynard Keynes (1883-1946)

Published in 2020 by IIIEE, Lund University, P.O. Box 196, S-221 00 LUND, Sweden,
Tel: +46 – 46 222 02 00, Fax: +46 – 46 222 02 10, e-mail: iiiee@iiiee.lu.se.

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This thesis was written in a tumultuous time. When Covid-19 swept across the globe it exposed us to our frailties and inequalities, but it also revealed our ability to adapt and transform our societies in the face of an imminent threat. The grand challenges that lie before us will require a united front to resolve, and whether we are physically together or apart, we are dependent on each other to strive. It is on that note that I want to express my deepest gratitude to all those who have supported me throughout my thesis journey.

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Abstract

Climate change is the greatest challenge of our time. Despite efforts to reduce greenhouse gas (GHG), the emissions contribution from global aviation is set to increase. Electric aviation has emerged as an alternative which could form part of the solution. Sweden, which is on the path to carbon neutrality and has a long history in aviation, could contribute to the global efforts in mitigating climate change through proliferating the electric aircraft. This thesis thus aims to inform the Swedish government on how it can contribute to the development and diffusion of electric aviation. Utilising the technological innovation systems (TIS) framework and lending concepts from the multi-level perspective (MLP), this thesis analyses electric aviation from a wider systems perspective to identify barriers to the development and diffusion of the electric aircraft as well as propose policy instruments to rectify them. Informed through a range of secondary data sources, 14 expert interviews and two observations, this thesis found several problems and underlying structural causes which hinder electric aviation. To spur electric aviation the government could implement a range of policy instruments as well as adjust framework conditions. Creating market incentives, providing infrastructure, and increasing the capacity of government agencies to leverage innovations, as well as creating new networks or balancing the actor-constellation in current networks and facilitating dialogue in them, may be important. Setting a clear agenda and goal is however key. In designing policy instruments and instrument mixes, several design criteria need to be considered as to effectively achieve policy goals. To transition to a new aviation paradigm, there needs to be a simultaneous focus on creation of the new and destruction of the old, and the current landscape changes resulting from the Covid-19 pandemic and increasing awareness of rapid climate change may constitute a window of opportunity to do so.

Keywords: electric aviation; battery-electric aircraft; technological innovation systems (TIS); multi-level perspective (MLP); innovation policy

Executive Summary

Climate change is the greatest challenge of our time, requiring unprecedented changes in all aspects of society. Global aviation's contribution to greenhouse gas (GHG) emissions is large and growing, and current pathways to sustainability are insufficient to be in line with the targets set out in the Paris Agreement. Electric aviation has emerged as an alternative that could form part of the solution, not only reducing emissions but also noise and increasing accessibility, and thus prosperity. Sweden has a long history in aviation as well as ambitious climate and transport policy objectives and therefore has the preconditions to contribute to the global efforts in mitigating climate change through proliferating the electric aircraft. In this light, this thesis aims to inform the Swedish government on policy instruments it could implement that contribute to the development and diffusion of electric aviation. Based on this overarching objective, three research questions have been formulated as follows:

RQ 1.1. What are the barriers to the development and diffusion of electric aviation in Sweden?

RQ 1.2. What are the underlying causes of these barriers?

RQ 1.3. How can these barriers and their underlying causes be addressed through policy intervention?

In order to answer these questions an understanding of how to approach the study of innovations and innovation policy was needed, and thus an extensive literature was conducted. In this literature review it was found that the success of an innovation is not only related to the activities inside individual firms or research institutes but is also shaped by the broad societal structure in which it is embedded. According to this view, electric aviation can be conceptualised as a technological innovation system (TIS), which constitutes the technology as well as the network of agents that interact with this technology under a particular institutional infrastructure for its generation, diffusion, and utilisation. A number of processes, conceptualised through a set of functions, are according to this perspective important for a TIS to perform well. By analysing the functioning of the TIS through these processes, problems can be identified which can be related to the presence or attributes in the societal structure. As such, a systems approach enables a holistic analysis to innovations, and provides for the systematic identification of barriers to an innovation as well as policy instruments to rectify these. Research has however also shown that the lock-in of fossil-based systems constitutes a particularly large barrier to the transition to sustainable innovations. The multi-level perspective (MLP) therefore argues that by focusing on the way in which the TIS interacts with the current system which the innovation seeks to replace, conceptualised as the regime, a yet more holistic perspective on the innovation and the transition processes is enabled.

This research thus set out to utilise the TIS framework, lending concepts from the MLP to study the functioning of the Swedish electric aviation TIS, while incorporating its interrelated regime dynamics in the analysis, in order to provide policy recommendations. Making use of 14 expert interviews, two observations, and numerous secondary sources, this research mapped out the structural components of the TIS and its interrelated regime context, and identified problems through a functional analysis, and could therefore answer the first research questions. By conducting a structural-functional analysis the structural causes of these problems could be identified, and the second research question could thus be answered. Utilising the literature and suggestions from the interviewees, these problems could be linked to policy instrument goals and specific policy instruments, and as such the third and final research question could be answered.

The research found several problems that hinder electric aviation, and these can be related to a number of structural causes. To spur electric aviation the government may need to implement a range of policy instruments as well as make adjustments to framework conditions. Creating market incentives, providing infrastructure, and increasing the capacity of government agencies to leverage innovations, are some important elements to such a policy intervention. Balancing incumbent actors' involvement in networks or the creation of new networks, as well as facilitating dialogue may be important as well. Most importantly the government must set the direction by creating a clear agenda and set concrete goals.

In the design of policy instruments several design criteria need to be considered, such as their level of stringency, support, flexibility and timing of introduction, and these policy instruments need to be combined in a portfolio in a congruent, consistent and coherent manner, as to effectively achieve policy goals. There needs to be a simultaneous focus on creation of the new and destruction of the old in order to transition to a new aviation paradigm, and the current landscape changes, as a result of the Covid-19 pandemic and increasing awareness of rapid climate change, may constitute a window of opportunity to do so.

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1 Introduction

Climate change is the defining issue of our time, requiring "rapid, far-reaching and unprecedented changes in all aspects of society" (IPCC, 2018, p. 1). In 2018, aviation accounted for 2.5 % of all energy related carbon dioxide (CO_2) emissions globally (ICCT, 2019). In addition to this, the non-CO_2 emissions are estimated to bring total greenhouse gas (GHG) emissions from aviation to 4-5 % of total global emissions (Lee et al., 2010). The International Air Transport Association (IATA) estimates that the number of air passengers worldwide will increase by 4 % per annum over the next 20 years (IATA, 2015). Meanwhile, the International Civil Aviation Organization (ICAO) has estimated that fuel consumption will increase by 200 % over the next 30 years given the current growth rate (ICAO, 2013). If this occurs and if land-based emissions follow an emission pathway in line with the targets set out in the Paris Agreement to limit the global temperature rise to well below 2°C above pre-industrial levels, emissions from aviation may account for 22 % of global emissions by 2050 (Cames, Graichen, Siemons & Cook, 2015). Simultaneously, aviation has been linked to a number of negative environmental effects, such as noise and air quality degradation, causing adverse health effects (Korzhenevych et al, 2014). There is a clear need to change these trends.

Aviation is considered important for global prosperity, as it contributes to economic growth, connects remote communities, helps to strengthen international cooperation and peace-building, as well as enhances emergency and humanitarian response capabilities during crises (ICAO, 2019). Dismantling aviation altogether is therefore difficult to justify. Efforts to reduce aviation emissions to date have however largely focused on achieving incremental fuel efficiency improvements, and although progress has been substantial, it has been negated by an increasing demand for air travel (Kim, Lee & Ann, 2019). Optimising air traffic management and reducing air travel volumes are two other commonly proposed mitigation strategies (Larsson, Elofsson, Sterner & Åkerman, 2019). Switching to alternative fuel sources is another option to achieving decreased aviation emissions, with biofuels considered to be the primary source in the near term (Rötger, 2012). While the technical suitability of biofuels has been successfully proven without requiring any modification to conventional airframe designs and engines (Rötger, 2012), increasing competition for biomass and land-use constraints casts doubts on the sustainability and viability of this option (Dicks, Campiche, De La Torre Ugarte & Hellwinckel, 2009; IPCC, 2014; McManners, 2016). The introduction of the hydrogen-powered aircraft is considered to be another, albeit very long run option, due to the low energy density of hydrogen, the difficulty of storing it onboard, and concerns surrounding the enhanced climate-affecting water vapour emissions (Cryoplane, 2003).

A recent entrant onto the stage of innovative solutions for sustainable aviation is the battery-electric aircraft, which produces zero emissions, and promises lower operating costs, reduced noise, and new capabilities that may open new lucrative markets (Brelje & Martins, 2019), increasing the dispersion of air services to smaller airports and previously unconnected areas (Smith et al, 2012). Although electric flight has been possible since the 1970s, it remained limited to light-weight experimental airplanes flying short distances, and solar-powered aircraft incapable of carrying passengers (Selkirk, 2020). Having benefitted from recent rapid advancements in battery technology (ABB, 2020), the battery-electric aircraft is now touted as a technology that may re-draw the map for transportation (Chalmers University of Technology, 2019), disrupting the industry by undermining the business models of leading engine makers, requiring new competencies and infrastructures, and changing the way people fly and perceive aviation (Hollinger, 2018).

Such systemic eco-innovations[1] tend to diffuse slowly due to the lock-in[2] effects of our incumbent fossil fuel-based systems, driven by path-dependent[2] increasing returns to scale (Suurs & Roelofs, 2014). The aviation system is considered to be particularly difficult to transform as a range of reinforcing forms of lock-in are at play, such as the long life of existing fleets, the large resources required to realise change, and the central importance of safety and security (IPCC, 2014; Lawson, 2012). Circumventing or breaking these lock-in effects and prompting innovation will therefore require substantial, sustained, and directed policy interventions (IPCC, 2014; Suurs & Roelofs, 2014). Although the preferred choice for regulating international activities such as aviation is international policy instruments, of which a global carbon tax on jet fuel is considered likely to be most efficient, these are difficult to agree upon (Larsson, et al, 2019). Existing international climate policies for aviation, (EU ETS[3] and CORSIA[4]), will not deliver the emission reductions necessary to achieve the 2°C target (Larsson et al, 2019), and consequently national aviation climate policy is needed (Lee, 2010; Larsson et al, 2019; Lawson 2012).

Sweden has a long history in aviation, an internationally recognised aerospace industry (Ministry of Enterprise and Innovation, 2005), and is considered to be one of the most advanced countries in terms of innovation worldwide (Chaminade, Zabala, & Treccani, 2010). Sweden is also considered a leader in the energy transition (IEA, 2019), with 58 % of Swedish electricity generation originating from renewable energy sources in 2017, a figure set to increase to 100% by 2040 (ET 2019:3). According to the *Swedish Climate Policy Framework* which came into effect on 1 January 2018, Sweden should achieve net zero GHG emissions by 2045 and thereafter achieve negative emissions, and all domestic transport emissions should be reduced with 70 % by 2030 compared with 2010, excluding domestic aviation[5] (Prop. 2016/17:146). The overall objective of Swedish transport policy is to ensure a socially and economically efficient and long-term sustainable transport supply for citizens and businesses throughout the country (Prop. 2008/09:93). In addition, this overarching objective is supplemented with a *functional objective* and an *impact objective,* which are equal. The functional objective is to provide basic accessibility with high quality and usability throughout the country, and the impact objective is to ensure that the design, function and use of the transport system is adapted to ensure that safety, environment and health are not compromised (Prop. 2008/09:93). The battery-electric aircraft could contribute to achieving these objectives by reducing noise and air pollution (impact objective), improving accessibility throughout the country (functional objective), and inducing a modal shift away from other fossil-driven modes of transport, and thereby reduce transport emissions (climate objective). Proliferating electric aviation could therefore be an opportunity for the country to achieve its objectives while contributing to the global effort to reduce GHG emissions and achieve long-term sustainability. While a body of literature exists on how to

[1] Eco-innovations are new products or processes which provide value while significantly decreasing environmental impacts (James, 1997). Innovations are considered systemic if they lead to fundamental changes in both social dimensions (values, regulations, attitudes, etc.) and technical dimensions (infrastructure, technology, tools, etc.) and in the relations between them (Suurs & Roelofs, 2014). While an eco-innovation is not necessarily radical or disruptive, a systemic innovation is (Suurs & Roelofs, 2014).

[2] The concept of path dependency implies that the economics of future technology-related decisions depend on previous decisions and investments (Arthur, 1989). As a consequence, suboptimal decisions taken today may become locked in to an inferior development pathway for decades, as changing that path becomes prohibitively costly (Sorrell & Sijm, 2003).

[3] The European Union Emissions Trading System (EU ETS) started in 2005 and uses tradable emissions allowances as a mechanism to steer emission reductions to sectors where they can be implemented at lowest cost (EU, 2017). Parts of the aviation sector have been included in the EU ETS since 2012, covering flights where both takeoff and landing are within the EU. The allowances issued for 2013-2020 correspond to 95% of emissions of 2008–2012, and from 2021 onwards, there is to be a linear annual reduction until 2064, when no additional allowances will be issued (EU, 2017).

[4] The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) came into force in 2019 and obliges airlines to offset their increase in emissions after 2020 by purchasing credits from emission mitigation projects outside the aviation sector (ICAO, 2018). The system is voluntary between 2020-2027, but becomes mandatory for all countries after that date. There are several exemptions (Larsson et al, 2019).

[5] Domestic aviation is excluded due to its inclusion in the EU ETS (Prop. 2016/17:146).

achieve socio-technical transitions[6] and proliferate eco-innovations, the design of policy instruments for innovation needs to be context-specific (Edler & Fagerberg, 2017). To date, no publicly accessible peer-reviewed literature addressing the issue on how to facilitate the development and diffusion of the battery-electric aircraft exists however, either in Sweden or in any other context, and therefore there is a need to fill this knowledge gap.

1.1 Aim and Research Questions

The Swedish government has tasked the government agency Transport Analysis with analysing developments regarding electric aviation, as well as suggesting policy measures which could be suitable to promote development and a transition to a greater use of electric aircraft (Ministry of Infrastructure, 2020). This thesis aims to inform the latter part of that assignment. Achieving this aim may contribute to resolving the problem of how to achieve the emissions reductions necessary for keeping in line with the targets set out in the Paris Agreement, as well as attain national climate and transport policy goals. Within this context the overall objective of this thesis can be formulated as follows:

How can the Swedish government contribute to the development and diffusion of electric aviation?

Based on this overarching objective, three research questions have been formulated as follows:

RQ 1.1. What are the barriers to the development and diffusion of electric aviation in Sweden?

RQ 1.2. What are the underlying causes of these barriers?

RQ 1.3. How can these barriers and underlying causes be addressed through policy intervention?

1.2 Definitions

In order to establish how certain concepts are used and interpreted within the scope of this thesis, this section provides an overview of some key concepts. While the term *electric aircraft* refers to an aircraft powered by electric motors, with electricity supplied through a variety of methods including batteries, ground power cables, solar cells, fuels cells etc., the term will in this thesis be used to denote a battery powered aircraft. *Drones* and electric aircraft share many similarities. The Swedish Civil Aviation Administration defines drones as any type of aircraft that does not have a pilot on board and can be controlled by a remote pilot or operate autonomously (LFV, 2019). The focus of this thesis is therefore aircraft which, at least in the current conceptual stage of development, has a pilot on board.

While the term *aeronautics* denotes the science of designing and building *aircraft*, the term *aviation* denotes the activities surrounding mechanical flight and the aircraft industry (Vinnova, 2017). Aeronautics can therefore be said to concern the development of the vessel, while aviation concerns the aspects surrounding the use of it. The terms *aircraft* and *aviation* will be used interchangeably to denote both the development and the diffusion, i.e. the use of the electric aircraft.

The terms *eco-innovation* and *sustainable innovation* denote an innovation which provides value while significantly decreasing environmental impacts or helps to achieve other social and economic

[6] The multi-level perspective (MLP) argues that transitions entail major changes in the "socio-technical systems" that provide societal functions such as mobility, housing, and sustenance (Geels, Sovacool, Schwanen, & Sorrell, 2017). These systems consist of a mix of technologies, supply chains, infrastructures, markets, regulations, user practices, and cultural meanings which are interdependent and co-evolving. The systems evolve over several decades, and the alignment of the different elements leads to path dependence and resistance to change (Geels et al, 2017).

sustainability-related objectives (Godin & Gaglio, 2019; James, 1997). Likewise, a *radical innovation* can be defined as an innovation which is a dramatic departure from existing products, and a *disruptive innovation* can be defined as an innovation which displaces the existing mainstream innovation in the mainstream market (Edwards-Schachter, 2018). A *systemic innovation* is one which leads to fundamental changes in both social and technical dimensions and in the relations between them (Suurs & Roelofs, 2014). As electric aviation can be considered to fit into all five of these categories, these terms will be used interchangeably throughout the thesis to denote the innovation electric aviation.

1.3 Ethical Considerations

The general ethical principles of research were applied to this study (Blaikie & Priest, 2019). It was designed with the aim of making a worthwhile contribution to solving an important social problem. It was supported but not funded by the government agency Transport Analysis. There was no conflict of interest on part of the author or civil servants at the agency, and no attempts at interference that could compromise the independence of research. Interview participants were given the option to remain anonymous or refrain from being directly cited. Written informed consent was obtained and participants were given the freedom to refrain from answering questions and to withdraw consent at any time throughout the duration of the project. The consent form can be found in Appendix A: Consent Form

While none of the participants opted for complete anonymity, some participants asked for their quotes to be included yet to remain anonymous, which was observed in order to avoid exposing sensitive information that could cause any participant to suffer a disadvantage from their participation in the study. Anonymity and confidentiality of participants were guaranteed, and results were reported faithfully. With permission from the participants, the interviews were recorded and transcribed in order to accurately relay provided information, and the participants approved the direct citations before publishing. The collected data was stored on the author's local hard drive and personal password-protected cloud service, as to ensure that there were no breaches of privacy. The academic integrity of the research was maintained through deliberate avoidance of plagiarism, pursuit of keeping high methodological standards, as well as efforts to disclose potential subjectivity or bias.

The research design has been reviewed against the criteria for research requiring an ethics board review at Lund University and has been found to not require a statement from the ethics committee.

1.4 Audience

The intended audience of the thesis is first and foremost civil servants at the government agency Transport Analysis who may use the research findings as a starting point for analysing and suggesting policy measures which could be suitable to promote a development and a transition to a greater use of electric aviation as part of their government assignment. The findings will ideally facilitate discussions surrounding the identification of innovation policy problems and the design of innovation policy instruments, which may lead to effective policy interventions and an increased capacity to conduct similar assignments in the future. This research may also provide useful industry-specific insights which could benefit actors involved or interested in the developments surrounding electric aviation and innovation in general in Sweden. Finally, the thesis may also be of interest to the innovation scholar community, as frameworks are constructed and applied in a novel manner and context, which may drive innovation policy knowledge development further.

1.5 Disposition

Chapter 1 introduced the research topic and described its wider context and significance. It also defined the problem, research aim, objective and questions. The chapter then provided a brief overview of key concepts, as well as outlined the ethical considerations and intended audience.

Chapter 2 reviews relevant literature and elaborates on concepts relating to public policy, policy instruments, and criteria for designing policy instruments and mixes. The chapter goes on to detail and discuss research developments that have led to the theoretical constructs which underpin innovation policy today. The chapter then outlines a conceptual framework, which builds on technological innovation systems (TIS) and the multi-level perspective (MLP) frameworks, and which is used to guide the research. The chapter concludes with a brief revision of previous similar studies of relevance to this research.

Chapter 3 provides a rationale for the research design and presents the methods and methodology used to collect and analyse data in order to answer the research questions. The chapter proceeds to define the scope and concludes by discussing the validity and reliability of the research findings.

Chapter 4 presents the analysis and findings. It begins by mapping the relevant structural elements, continues with determining the technology phase of development and assessing the functioning of the innovation system in relation to the determined phase. It then goes on to identify problems which hinder the functioning of the innovation system and identifies the structural causes underlying these problems. It concludes by presenting four key issues that may require particular policy attention.

Chapter 5 discusses and evaluates the findings in relation to the reviewed literature and reflects on the results of the study.

Chapter 6 concludes the thesis, details practical implications and provides recommendations for the intended audience, as well as outlines potential areas for future research.

2 Literature Review

In this chapter, theoretical aspects of innovation policy design are presented, and the concepts scrutinised in relation to their contextual relevance. Section 2.1 starts by laying the foundation for a basic understanding of public policy, providing examples of policy instrument typologies, and common criteria for designing policy instruments and instrument mixes. The subsequent sections detail and discuss developments that have led to the theoretical constructs which underpin innovation policy today. Section 2.3, outlines the conceptual framework which is used to guide the thesis, and the chapter subsequently concludes by briefly summarising earlier research which provide insights to this study.

2.1 Public Policy

In order to provide policy recommendations, we need an understanding of what policy actually entails. *Public policy* can quite simply be defined as “what government chooses to do or not to do” (Dye, 1972, p. 2). While this definition helps to underscore the notion that policies are conscious choices, rather than accidental occurrences (Howlett, 2011), it is not particularly helpful from an analytical perspective, as it says nothing about the *content* of government decisions: what it is that governments are choosing to do, or why (Colebatch & Hoppe, 2018). Lasswell (1958) also defines public policies as government decisions but notes that these decisions are composed of two interrelated elements: policy goals and policy means. *Policy goals* may be defined as the aims and expectations of governments in deciding to pursue (or not) a course of action, *policy means* on the other hand, may be defined as the techniques developed in order to achieve these goals (Howlett, 2011).

2.1.1 Policy instruments

Policy means are in the literature usually termed *policy instruments* or *measures* and are generally classified into three categories: (1) regulatory instruments, (2) economic instruments, and (3) informative instruments (Bemelmans-Videc, Rist & Vedung, 2003). Regulatory instruments are measures used to influence actors through formulated rules and directives which mandate behaviour and are usually backed by threats of sanctions in cases of non-compliance. Economic instruments provide specific pecuniary incentives or disincentives to influence the behaviour of actors. Finally, informative instruments are measures undertaken to influence addressees using mediated or interpersonal transmission of information (Bemelmans-Videc, Rist & Vedung, 2003).

In a memorandum from Transport Analysis (PM 2018:2), the Swedish government agency this thesis aims to inform, a different categorisation of policy instruments is made which serves as a common reference in the agency’s work on policy analysis. Apart from regulatory, economic and informative instruments, the agency adds nudging, social-, infrastructure- and traffic planning, negotiations and agreements, public procurement, and research and innovation. Nudging concerns the use of behavioural science knowledge to design and present decision-making situations in a way that give individuals a "push" in the desired direction and may involve changing the physical environment or presenting information in a specific way. Social-, infrastructure- and traffic planning concerns the use of planning to steer travel and transport patterns, either by creating practical conditions for desirable travel and transport patterns or designing in such a way to make unwanted behaviours more difficult. Negotiations and agreements entail influencing the actions of actors by negotiating with and making agreements with the actors in question. Agreements are often used when there are limited opportunities to influence actions in other ways and may involve both private actors and public actors such as municipalities. Public procurement involves the use of public funds to finance public purchases of goods and services. By setting requirements, procurement can steer actors operating in the market for the procured goods and services in a socially desirable direction.

Transport Analysis discusses whether research and innovation can be considered a policy instrument category as it concerns how the public sector promotes and steers the activities of actors within research and innovation, in order to generate new knowledge, new technology and find new solutions to problems and challenges, which may be achieved using a number of instruments. The agency argues that if support for research and innovation can be characterised as belonging to its own instrument category, the steering can be said to occur at two different levels. The first is through the public prioritisation of specific research areas, the level of financing, and criteria for obtaining financing dedicated to this area. At this level, the public intervention for research and innovation is regarded as an economic instrument, with elements of governance through collaboration and partnership. The second level involves support for research and innovation which can lead to the development of new transport-related solutions that are made available for the actors within the transport system. An example is the use of innovation procurement, which is the procurement of prior unknown solutions to a defined problem or solutions that are not yet established on any market. A related example is the use of catalytic procurement, whereby an authority encourages the development and diffusion of solutions to fill the need of various other users, such as through the coordination of technology competitions. Support at this level steer in a similar way to social-, infrastructure- and traffic planning, namely by facilitating the transport system's actors to behave in a way that increases the chances of achieving the transport policy goals. Although the focus of the memorandum is on policy instruments directed at private actors, public organisations can also govern the actions of other parts of the public sector, by for example issuing appropriation directions, i.e. deciding which and how activities are to be conducted under public auspices (PM 2018:2).

2.1.2 Designing Policy Instruments and Mixes

While all instrument types come with their own set of advantages and disadvantages, the importance of a policy instrument's design features on policy instrument effectiveness has become increasingly highlighted in the literature in recent years (Kemp & Pontoglio, 2011). *Stringency*, the ambition level of an instrument, often associated with regulatory and economic instruments (Kemp & Pontoglio, 2011), and *flexibility,* the extent to which actors are allowed to freely choose in which ways to comply with an instrument (Kivimaa & Mickwitz, 2006), are considered to be two important design criteria. The *level of support*, meaning the magnitude of positive incentives provided by a policy instrument, relevant particularly for instruments providing financial incentives, as well as *timing,* meaning the moment at which an instrument becomes effective and the use of phase-in periods, are considered to be important design criteria as well (Steinhilber, Ragwitz, Rathmann, Klessmann & Noothout, 2011). In addition, scholars have in recent years started to recognise the need to combine multiple instruments to achieve policy goals. Howlett and Rayner (2013) suggest that such policy mixes, if designed appropriately, can be expected "to have a higher probability of delivering a specific outcome than some other configuration" (p. 171). To achieve effectiveness and efficiency of policy mixes, a set of design criteria is thought to have to be fulfilled. *Consistency* is one such design criteria and means that policy instruments reinforce rather than undermine each other in pursuit of policy goals. *Coherence* is achieved when multiple policy goals co-exist with each other and instrument norms in a logical fashion (Howlett & Rayner 2007), and *congruence* is attained when goals and instruments work together in a unidirectional and mutually supportive manner (Kern & Howlett, 2009).

Edler and Fagerberg (2017) hold that the design of policy instruments should be context-specific and may be influenced by our (theoretical) understanding of the subject matter, lessons learned from practice, and the involvement of stakeholders at different levels of society. While such a stance signals that policy instruments are neutral devices, the formulation of policy invariably entails a selection - of which objectives to emphasise, which problems to address, which policy instruments to choose etc. (Borrás, & Edquist, 2013). The selection can, by definition, never be politically neutral. The underlying logics for why, when, and how government should intervene in the economy are often contested and change over time, through an interplay between policy, theory and practice, resulting in a range of theoretical approaches (Chaminade & Edquist, 2012). In order to arrive at theoretical constructs that can conceptually guide this thesis, the following sections will try to detail these developments, with a specific lens towards policy for innovation.

2.2 Policy Logic

Innovation is a phenomenon as old as mankind itself, and while innovation policies, interpreted as policies that affect innovation, may have existed for centuries, the term 'innovation policy' only became popular among users from the mid-1990s onwards (Edler & Fagerberg, 2017). While there are many different perspectives on innovation, the broad perspective, frequently applied in contemporary innovation studies, understands innovation as "the introduction of new solutions in response to problems, challenges, or opportunities that arise in the social and/or economic environment" (Edler & Fagerberg, 2017, p. 4). As Edler and Fagerberg (2017) elaborate, policies targeting and affecting innovation were pursued by governments long before the birth of the modern social sciences, and theoretical constructs justifying said policies can thus be regarded as "*ex post* rationalizations of already existing practices" (p.6). Such constructs are considered useful as they provide legitimation, and elucidate how and why a policy works, thereby underpinning the process of designing, implementing, and revising policy (Edler and Fagerberg, 2017).

2.2.1 Market Failure Approach

Justification for political action in innovation traces back to the emergence of neoclassical economic theory (Wanzenböck & Frenken, 2020), with the creation of the 'market failure' approach to innovation policy in the decades following World War II (Edler & Fagerberg, 2017). According to this view, free markets produce the optimal result for society (Edler & Fagerberg, 2017), and policy intervention in innovation is legitimised only if an efficient functioning of markets is inhibited (Wanzenböck & Frenken, 2020). This view assumes that the creation of new knowledge is the most important source of innovation, and that the economic gains of this knowledge often cannot be fully appropriated by those creating it (Edler & Fagerberg, 2017). As knowledge can be accessed and exploited free of charge by anyone, the incentives to invest in the creation of knowledge is dramatically reduced. The result is thus an "underinvestment in the creation of new knowledge in relation to what would be desirable for society as a whole" (Edler & Fagerberg, 2017, p. 7). Such 'market failure' may justify policy intervention with the aim of increasing investment in science toward the socially optimal level (Edler & Fagerberg, 2017). The policy instruments especially supported within this view concern investment in the public production of knowledge, the subsidisation of research and development (R&D) in private firms, and the strengthening of the incomplete property rights (IPR) regime (Edler & Fagerberg, 2017).

2.2.2 Innovation System Approach

While the decades following World War II and leading up to the early 1970s were marked by economic prosperity, the subsequent decades saw a considerable downturn (Edler & Fagerberg, 2017). The role of technological innovation as a motor for long-run economic growth and increased international competitiveness became increasingly acknowledged, and the question of whether and how policy could contribute to raising innovation activity and revitalise the economy came up on the agenda (Edler & Fagerberg, 2017; Schot & Steinmueller, 2018). At the same time, scholars had come to the realisation that countries differ not only in terms of economic performance but also in the patterns of creation and diffusion of innovation, as well as the national frameworks supporting it (Edler & Fagerberg, 2017). These developments laid the foundation for the national innovation system (NIS) approach to innovation policy, which emerged in the late 1980s, with major publications by Freeman (1987), Lundvall (1988, 1992), and Nelson (1988, 1993). Edler and Fagerberg (2017) write that there have been discussions concerning whether the NIS approach should be characterised as an approach, theory or framework, and argue that it is best understood as a synthesis of several bodies of research of relevance for innovation, such as Schumpeter's classic works, empirical findings on what influences innovations, and the 'new' evolutionary economics that surfaced around 1980 (Edler & Fagerberg, 2017).

In this view, innovation is regarded as a social phenomenon, the consequences of which depend not only on the activity inside firms, but also on the broader social and economic environment, which in turn is viewed as functioning as a resource or enabler for firm-level innovation, which policy is believed to be able to contribute to (Edler & Fagerberg, 2017). Like the market failure approach, this view places emphasis on learning, yet extends beyond R&D, arguing that processes of innovation are characterised by learning by doing, learning by using, and learning by interacting among several different kinds of actors and agents (Edquist, 1997). These may be other firms, such as suppliers, customers and competitors, but could also be universities, investment banks, government ministries, etc. Apart from learning, the behaviour of firms is also shaped by institutions that constitute constraints or drivers for innovation, such as laws, social rules and technical standards. Together these components and the relations among them form the system constituents. This system has a function, i.e. it is performing or achieving something. The system of innovation can thus be broadly defined as one which includes "all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion and use of innovations" (Edquist, 1997, p.14), and can be found illustrated in
Figure 1.

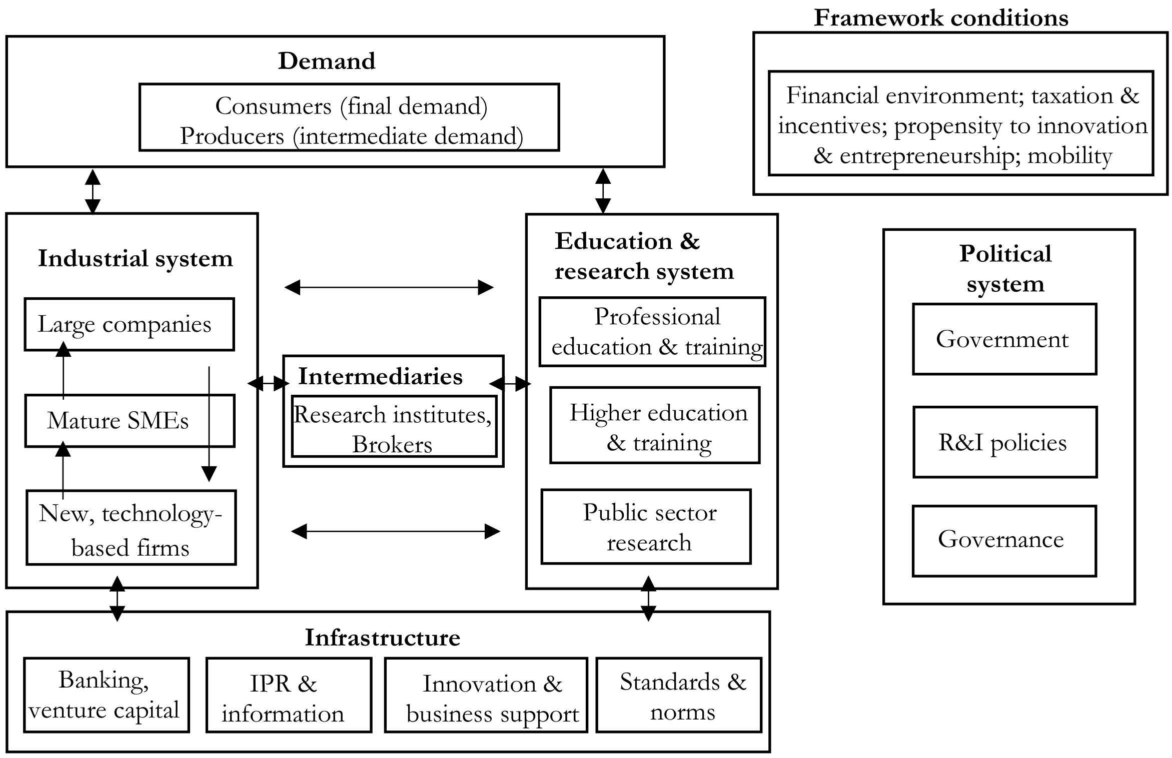

Figure 1. Generic illustration of a system of innovation.

Note. Adapted from Arnold, E. & Kuhlman, S., (2001). *RCN in the Norwegian Research and Innovation System*. Technopolis, Brighton.

In early works on national systems of innovation, mainly structural constituents were used to explain why the pattern of innovation differs between countries (Edquist, 1997). Since, empirical research informing this view has shown how successful innovation is dependent on a number of factors, such as knowledge, financial resources, etc., which have been regarded as provided within the nation (Edler & Fagerberg, 2017). The provision of these various factors has in the innovation systems literature been labelled functions, processes or activities (Edquist & Chaminade, 2006; Weber & Truffer, 2017; Wieczorek & Hekkert, 2012). If the system does not sufficiently provide for these factors, it is considered that 'system failure' (or 'problem' or 'weakness') is hampering innovation activity. The system of innovation view thus suggests that the state should go further than try to correct market failures, to also identify and rectify system failures (Edler & Fagerberg, 2017). Policies aimed at correcting system failures are often horizontal, meaning that they try to establish an institutional system conducive to innovation, with for example policies that seek to develop capabilities, provide infrastructure, or support networking between actors (Mazzucato & Penna, 2016).

Since its emergence, a number of different innovation system concepts have been put forward in the literature: national (Freeman 1988; Lundvall 1992; Nelson 1993) or regional innovation systems (Doloreux, 2002) when a geographical space is a unit of analysis; sectoral innovation systems (SISs) that focuses on a group of firms that develops and manufactures the products of a specific sector, and generates and uses the technologies of this sector, that often go beyond national borders (Malerba 2002); and technological innovation systems (TISs) that is not confined to national borders either, but focuses on a specific technology (Carlsson & Stankiewicz 1991; Carlson, Jacobsson, Holmén & Rickne, 2002).

2.2.3 Transformational Approach

A third framing for policy intervention in innovation has recently emerged as a response to the need to solve 'grand societal challenges' facing modern societies, such as climate change, inequality, and biodiversity loss (Haddad, Nakić, Bergek & Hellsmark, 2019). This framing, which has been dubbed 'transformative innovation policy' (TIP), can be characterised as consisting of two diverging strands of thought: one which argues that previous innovation policy research can inform the transformative paradigm (Fagerberg, 2018), and another which argues that this new framing should depart from research on sustainable transitions (Schot & Steinmueller, 2018), or from the mission-oriented framework (Mazzucato, 2018). The diverging views agree on two points: that knowledge on how innovation policy can be used to address grand challenges is needed, and that delivering transformative policies requires changes in practices and associated administrative and organisational capacities of public organisations (Haddad et al., 2019). However, the understanding of what characterises the transformative innovation policy paradigm, its roots and branches, as well as the different frameworks contributions on practical aspects of the policymaking process is currently quite unclear, according to Haddad et al. (2019).

The mission-oriented innovation policy approach departs from government-led development and mainstream economics (Haddad et al., 2019). Policies within the mission-oriented approach target the development of specific technologies that are in line with state-defined goals ('missions') (Mazzucato & Penna, 2016), which should be "bold, inspirational, with wide societal relevance" (Mazzucato, 2018, p. 811). Proponents of this view point to learning from such mission-oriented feats that led to putting humans on the moon (Mazzucato, 2016). These feats required not only the collaboration between the public and private sectors, but also that the state did not limit its role to incentivising, facilitating or de-risking the private sector, but rather took (public) risks through choosing a particular direction of change. Setting a new direction requires the creation and shaping of new markets, which is achieved primarily through direct state investments (Mazzucato, 2016). Therefore, innovation has both a rate and direction, "where the rate is dependent on the intensity of resources invested and the direction is guided by choices made based on shared visions, goals and policies" (Mazzucato & Robinson, 2016, p. 37). In order for the state to organise its market-creating role, it must build its absorptive capacity, meaning that public agencies should learn in a process of investment, discovery and experimentation (Mazzucato, 2016). This view also stresses the need for developing concrete indicators and methods to evaluate government investments (Mazzucato, 2014), as well as the need to share risks and rewards among public and private actors (Mazzucato, 2016). Policies employed within this approach mainly concern the creation of markets, employing instruments such as public procurement of innovation (PPI) (Miedzinski, Mazzucato, & Ekins, 2019).

Another strand of thought within the transformative innovation policy paradigm departs from theoretical work on socio-technical transitions (Haddad et al., 2019). The understanding of transitions builds primarily on the multi-level perspective (MLP) (Geels, 2002), which was developed in the field of innovation studies, drawing insights from evolutionary economics, sociology of technology, and neo-institutional theory (Geels, 2012). The multi-level perspective distinguishes socio-technical transformation dynamics at three levels of aggregation: niches (micro-level), regimes (meso-level), and landscape (macro-level) (Weber & Rohracher, 2012). Niches are the spaces protected from normal market forces within which technological novelties are developed. These act as a source of variety, testbed and 'engine for change' (Weber & Rohracher, 2012). The regime level represents the deep-structural rules, such as shared beliefs, norms, standardised ways of doing things, heuristics, and rules of thumb, that coordinate and guide actor's perceptions and actions (Geels, 2012). Through their coordinative effects, socio-technical regimes account for the stability of existing socio-technical systems, which encompass not only firms and the activities of engineers, but also other social groups such as users, policy makers, special-interest groups and civil society actors. Due to lock-in mechanisms and path dependence, innovations within existing regimes are mostly incremental, following technical trajectories, and the regimes are thus resistant to both technological and social transitions. The landscape level represents the wider context which influences niche and regime dynamics, including spatial structures, political ideologies, societal values, beliefs, concerns, the media landscape and macro-economic trends (Geels, 2012).

According to this framework, transitions generally come about through the interaction between processes at different levels: (a) innovations within niches build up internal momentum, (b) changes at the landscape level creates pressure on the regime, and (c) destabilisation of the regime create windows of opportunity for niche innovations to develop and diffuse (Geels, 2012), as can be found illustrated in Figure 2. Existing socio-technical systems may decline because of pressure from niche innovations, but they may also be phased-out deliberately to create space for the accelerated diffusion of niche innovations (Köhler et al, 2019). Proponents of this view argue that innovation policy should be designed with a transition goal in mind, focusing on the phasing out of unsustainable technologies (Alkemade, Hekkert & Negro, 2011). Such a phase-out would result from destabilisation policies targeting the regime, an example of such a policy instrument is a so-called control policy which aim for the internationalisation of externalities such as the social and environmental costs of carbon emissions (Kivimaa & Kern, 2016).

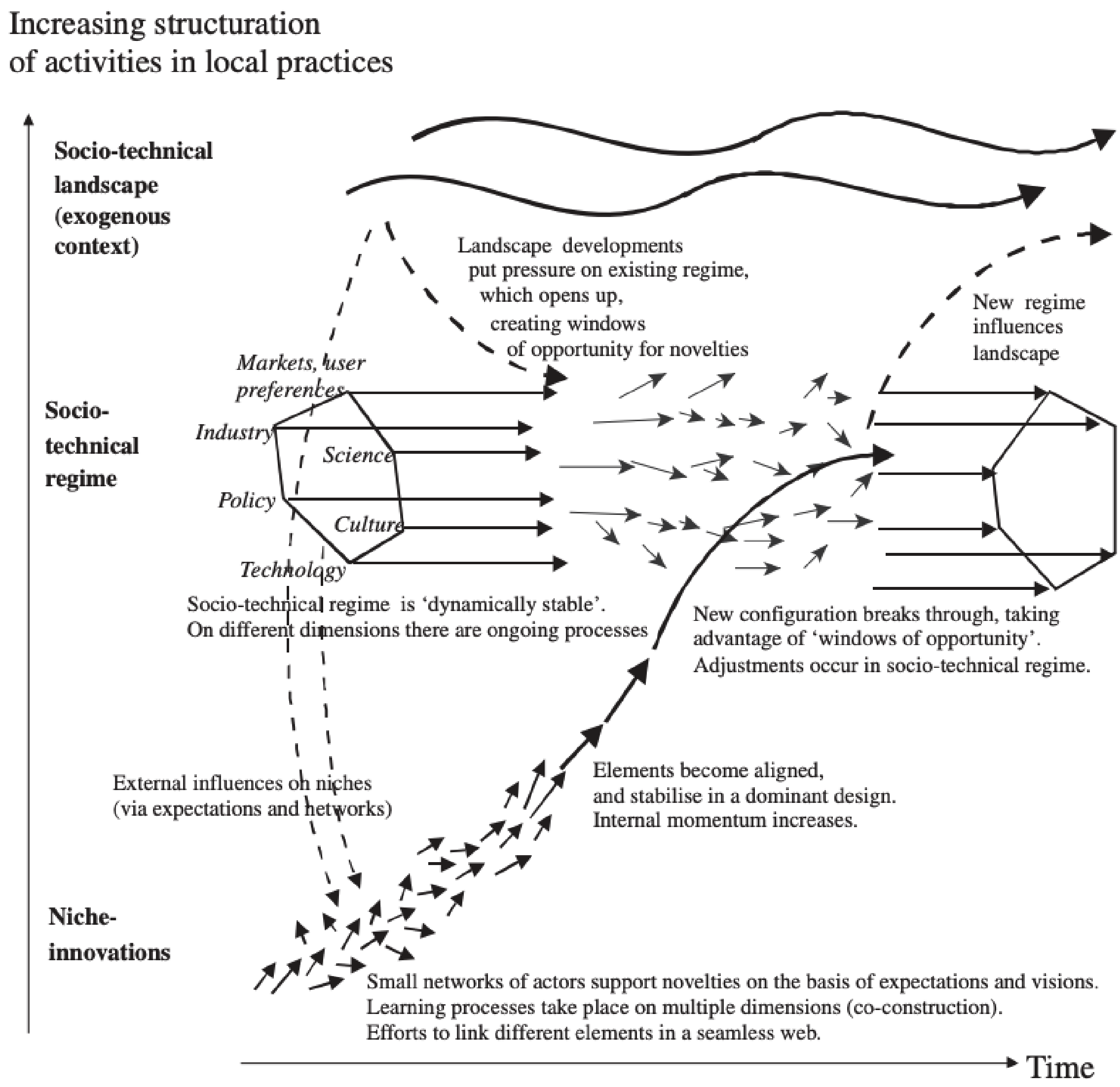

Figure 2. Multi-level perspective on transitions.
Note. Reprinted from Geels, F. W. (2012). A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies. *Journal of Transport Geography*, 24, 471–482.

2.2.4 Theoretical Discussion

The appeal of the market failure approach to innovation policy lies in its simplicity, according to Edler and Fagerberg (2017). In contrast, Swann (2010) considers the approach to be hard to understand as market failures and related concepts are difficult to define and quantify. It has also been criticised for applying a static perspective to a dynamic phenomenon (Mazzucato, 2016), and for being inconsistent with empirical findings on innovation processes (Edler & Fagerberg, 2017). Other authors criticise the market failure approach for mistakenly conflating information and knowledge, assuming that knowledge is as easily acquired as information (Metcalfe, 2005), as it is impossible for any actor to know 'everything' of relevance for the solution of an economic problem (Hayek, 1945). Although market failures remain an argument invoked as a rationale for innovation policy, especially to justify public provision of basic research, it is increasingly viewed as inadequate for the justification and guidance of the design and implementation of innovation policy more broadly (Mazzucato & Semieniuk, 2017).

The appeal of the innovation system approach to innovation policy lies in its more holistic perspective on innovation processes, and its ability to capture the embedded nature of innovation (Chaminade & Edquist, 2006). Dantas (2005) argues that policymakers appreciate the approach as it provides a coherent analytical tool that helps to identify context-specific factors that influence systems of innovation, as well as a prescriptive tool that indicates how to design policies that respond to the specific needs of the system under consideration. The innovation system approach has however been criticised for reducing the role of the state to that of a facilitator rather than creator of change (Mazzucato, 2016). Weber and Rohracher (2012) argue that the fixing of system failures leads to a focus on the supply-side of innovation, and that such policies remain silent on the content of innovations. The importance of demand-side policy instruments has however been recognised within the innovation systems literature in recent years (Borrás & Edquist, 2013). Alkemade, Hekkert and Negro (2011) argue that the approach does not have a regime shift objective, and the policies that result may thus strengthen existing unsustainable regimes. Finally, the innovation systems approach has been criticised for being too inward-oriented and not taking wider systems perspectives into account, and thereby failing to account for societal development embedding and competition with existing technologies (Markard, Raven & Truffer, 2012; Weber & Rohracher 2012).

The two strands of transformative approaches have different points of departure, yet have a shared understanding of the key characteristics of transformative innovation policy: a focus on directionality and in particular a focus on grand societal challenges; a more active and demanding government role; and broad stakeholder involvement throughout the policy process (Haddad et al., 2019). The mission-oriented approach suggests that the state should "pick the willing" rather than include all actors in missions. It also emphasises clear and measurable goals to a larger extent than the transitions-oriented approach, which instead emphasises the need for destabilising policies targeting current socio-technical regimes when designing policy mixes (Haddad et al., 2019. The mission-oriented approach is considered to be relevant for the transitions research community as it focuses on tackling societal challenges rather than pushing innovations, and seen as closely aligned with existing notions such demand-based innovation policy, policy-induced innovation, as well as with new innovation policy frameworks such as challenge-led innovation and dedicated innovation systems (Hekkert, Janssen, Wesseling, & Negro, 2020). The approach has however been criticised for lacking a framework that can be used to map and evaluate innovation dynamics that contribute to completing a societal mission, and to thereby design appropriate intervention strategies (Hekkert et al, 2020), and it is therefore considered to constitute 'fuzzy' policymaking (Brown, 2020).

The strength of the multi-level perspective is considered to lie in its ability to put transition processes in a broader context and that it thereby manages to capture interaction with the system environment (Markard & Truffer, 2008). The approach is however considered to be less powerful when it comes to the concepts and tools developed to investigate innovation dynamics at the niche level, and that it thus lacks in analytical power when investigating how to proliferate innovations (Markard & Truffer, 2008). The idea of a third frame of innovation policy has however been challenged (Haddad et al., 2019). Diercks, Larsen and Steward (2019) hold that in practice the transformative innovation policy paradigm is "layered upon but not fully replacing earlier paradigms of science and technology policy and innovation systems policy" (p. 880). Additionally, Fagerberg (2018) argues that the existing knowledge base in innovation policy studies is sufficient for addressing and discussing the grand challenges of today.

While the idea that a new innovation policy paradigm has emerged is contested, it is clear that innovation policy priorities need to go beyond innovation-based competitiveness and economic growth to address the grand societal challenges facing modern societies. Sustainable innovations need to replace unsustainable innovations. As such, there is reason to combine lessons from innovation system approaches on how to identify and rectify system failures to facilitate the emergence of innovations, and transformative approaches on how to upscale such an innovation, and destabilise and phase-out incumbent regimes.

2.3 Conceptual Framework

Several authors have linked the literature on innovation systems and sustainability transitions (Alkemade, Hekkert, & Negro, 2011; Kivimaa & Kern, 2016; Raven & Walrave, 2018; Weber & Rohracher, 2012). In the context of sustainability transitions, the TIS approach is considered useful to understand how radical innovations with sustainability promise come about, due to its focus on technologies and their socio-economic and institutional environment (Wieczorek, 2014). A TIS can be defined as a "network of agents interacting in the economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology." (Carlsson & Stankiewicz, 1991, p. 94). The static perspective of innovation system approaches wherein structural system components are mapped offers only inventory-like descriptions of innovation systems (Uyarra, 2010). According to Scordato, Klitkou, Tartiu, and Coenen (2018) this critique has been most readily addressed by the literature on TIS, which has directed attention to the activities or processes that are important for innovation systems to perform well, conceptualised through a set of functions, defined in two programmatic papers by Bergek, Jacobsson, Carlsson, Lindmark and Rickne (2008) and Hekkert, Suurs, Negro, Kuhlmann and Smits (2007). According to Hekkert et al. (2007) these system functions are composed of entrepreneurial activities, knowledge development and diffusion, guidance of the search, market formation, resource mobilisation, and legitimacy creation, see Table 1 for a summary of these functions. A functional analysis shows the dynamics of a specific innovation system in a defined moment in time and clarifies how the innovation system is functioning (Wieczorek & Hekkert, 2012).

Table 1. Key processes of innovation systems

Key process	Description
F1 Entrepreneurial activities	In this process entrepreneurs translate knowledge into business opportunities, and eventually innovations, through market-oriented experiments.
F2 Knowledge development	This process refers to learning activities, on emerging technology, markets, networks and users. The activities include learning-by-searching and learning-by-using. Both are at the heart of any innovation process.
F3 Knowledge diffusion	This process encompasses all activities that relate to the diffusion of knowledge among actors through learning-by-interacting.
F4 Guidance of the search	This function refers to those processes that lead to a clear goal for the development of new technology based on actors' expectations, articulated user demand and societal discourse. This process enables selection, which guides the distribution of resources.
F5 Market formation	This process involves activities contributing to the creation of demand for new technology. In early phases of development these can be small niche markets but later on larger markets are required to facilitate cost reductions and incentives for entrepreneurs to move in.
F6 Resource mobilisation	This function concerns allocation of financial, physical and human capital as necessary basic inputs for all processes in the innovation system. Unavailability of these resources hampers all other system activities.
F7 Legitimacy creation	Innovation is by definition uncertain. This process refers to activities that counteract resistance in the incumbent system and provide a certain level of legitimacy for actors to commit investment and adopt the new technology.

Note. Adapted from Wieczorek, A., J. (2014). Towards sustainable innovation: Analysing and dealing with systemic problems in innovation systems. (Unpublished doctoral dissertation). Utrecht University, Utrecht, Netherlands

Wieczorek and Hekkert (2012) argue that both the structural and functional analyses are useful analytical tools and combine them to build a comprehensive framework for understanding the dynamics of innovation systems. The structural dimensions of a TIS according to Wieczorek and Hekkert (2012) consist of actors, institutions, interactions, and infrastructure. In the systematic typology developed by the authors, as elaborated in

Table 2, the structural elements are delineated into several sub-categories. Actors are delineated according to their role in the economic activity: and includes companies, knowledge institutes, government, non-governmental organisations, and other parties such as legal and financial agencies. Institutions encompass soft institutions such as norms and shared concepts which are organised by hard institutions such as standards and regulations. Interactions are the relationships or links between people and include those at the levels of networks and those at the level of individual contacts. Finally, infrastructure consists of physical infrastructure such as buildings and roads; knowledge infrastructure such as expertise and know-how; and financial infrastructure such as subsidies and grants (Wieczorek & Hekkert, 2012).

Table 2. Structural dimensions of TIS

Structural dimensions:	**Subcategories:**
Actors:	- Civil society - Companies: start-ups, SME's, large firms, MNC's - Knowledge institutes: universities, technology institutes, research centres, schools - Government - NGO's - Other parties: legal organisations, financial organisations/banks, intermediaries, knowledge brokers, consultants
Institutions:	- Hard: rules, laws, regulations, instructions - Soft: customs, common habits, routines, established practices, traditions, ways of conduct, norms, expectations
Interactions:	- At the level of networks - At the level of individual contacts
Infrastructure:	- Physical: artefacts, instruments, machines, roads, buildings, networks, bridges, harbours - Knowledge: knowledge, expertise, know-how, strategic information - Financial: subsidies, fin programs, grants etc.

Note. Reprinted from Wieczorek, A., & Hekkert, M. P. (2012). Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. Science and Public Policy, 74–87.

A functional analysis 'signals' problems in the system, the source of which can be linked to the presence or properties of the structural elements: 1) the presence or capabilities of certain actors, 2) the presence or capacity/quality of the institutional set-up, 3) the presence or quality/intensity of interactions and 4) the presence or quality/capacity of infrastructure - a typology based on the work of Klein-Woolthuis, Lankhuizen and Gilsing (2005). Table 3 exemplifies how a coupled functional-structural analysis could be used to identify the above-defined systemic problems. According to Wieczorek and Hekkert (2012) the typology does however not suggest that all possible actors, types of infrastructure etc. need be 'present' in every system, as it would be contrary to the emergent nature of innovation, instead who to involve and to what capacity should be dependent on the system under analysis and its socio-economic and political environment. A complete overview of system dimensions and problems can aid in thoroughly analysing the system, and "to stimulate such combinations of elements that in [the analyst's] view have the greatest chances to stimulate innovation and desired e.g. sustainable orientation of the system." (Wieczorek & Hekkert, 2012, p. 80).

Table 3. Systemic problems based on functional-structural analysis of an innovation system

System function	**Structural element**	**Systemic problem**	**(Type of) systemic problem**
F1 Entrepreneurial activities	Actors	Actors problem	Presence?
			Capabilities?
	Institutions	Institutional problem	Presence?
			Capacity/quality?
	Interactions	Interaction problem	Presence?
			Intensity?/quality?
	Infrastructure	Infrastructural problem	Presence?
			Capacity?/quality?

Note. Adapted from Wieczorek, A., & Hekkert, M. P. (2012). Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. *Science and Public Policy*, 74–87.

Wieczorek and Hekkert (2012) argue that a coupled functional-structural analysis leads to a precise identification of the factors that block specific functions and thereby hinder the development of the innovation system. As such, addressing different types of problems requires different types of instruments. The selection of policy instruments cannot depend only on the identified problems however, but also on "the instruments' mutual interactions, the socio-political and economic conditions of the surrounding environment, the impact of other, perhaps competing TISs" (Wieczorek & Hekkert, 2012, p. 86). To guide this selection the authors put forth a number of systemic policy goals which allows for mutual reinforcement, coherence and orchestrated impact of instruments. These goals as well as examples of individual instruments that can be implemented to achieve those goals are elaborated in Table 4.

Table 4. Systemic problems linked to systemic instrument goals and examples of individual instruments

Systemic problem	**(Type of) systemic problem**	**Systemic instrument goals**	**Examples of individual instruments**
Actors problem	Presence?	Stimulate and organise the participation of relevant actors (1)	Clusters; new forms of PPP, interactive stakeholder involvement techniques; public debates; scientific workshops; thematic meetings; transition arenas; venture capital; risk capital
	Capabilities?	Create space for actors capability development (2)	Articulation discourse; backcasting; foresights; roadmapping; brainstorming; education & training programmes; technology platforms; scenario development workshops; policy labs; pilot project
Interaction problem	Presence?	Stimulate occurrence of interactions (3)	Cooperative research programmes; consensus development conferences; cooperative grants & programmes; bridging instruments (centres of excellence, competence centres); collaboration and mobility schemes; policy evaluation procedures; debates facilitating decision-making; science shops; technology transfer
	Intensity/ quality?	Prevent too strong and too weak ties (4)	Timely procurement (strategic, public, R&D-friendly); demonstration centres; strategic niche management; political tools (awards and honours for innovation novelties); loans/guarantees/tax incentives for innovative projects or new technological applications; prizes; CAT; technology promotion programmes; debates, discourses, venture capital; risk capital
Institutional problem	Presence?	Secure presence of hard and soft institutions (5)	Awareness building measures; information & education campaigns; public debates; lobbying, voluntary labels; voluntary agreements
	Capacity?/ quality?	Prevent too weak and too stringent institutions (6)	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms
Infrastructural problem	Presence?	Stimulate physical, financial and knowledge infrastructure (7)	Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs
	Capacity?/ quality?	Ensure adequate quality of the infrastructure (8)	Foresights; trend studies; roadmaps; intelligent benchmarking; SWOT analyses; sector & cluster studies; problem/needs/stakeholders/solution analyses; information systems (for programme management or project monitoring); evaluation practices & toolkits; user surveys; databases; consultancy services; tailor-made applications of group decision support systems; knowledge management techniques; TA's; knowledge transfer mechanisms; policy intelligence tools (policy monitoring & evaluation tools, systems analyses); scoreboards; trendcharts

Note. Adapted from Wieczorek, A., & Hekkert, M. P. (2012). Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. *Science and Public Policy*, 74–87.

The instruments that Wieczorek and Hekkert (2012) suggest are predominantly *systemic*, meaning that they aim at supporting the functions operating at the innovation system level. In the innovation policy literature, it is commonly argued that emerging socio-technical systems require not only systemic instruments, but also *supply push* (also termed *technology push*) instruments, which aim at supporting the provision of knowledge inputs, and *demand pull* instruments which aim at supporting market formation and diffusion (Söderholm et al, 2019). The supply push and demand pull instruments represent the engines of innovation policy, and the systemic instruments are seen as able to help that engine run more efficiently. Although Wieczorek and Hekkert (2012) aim to suggest systemic policy instruments, they also include several supply push instruments, such as R&D grants and patent laws, as well demand pull instruments, such as loan guarantees and voluntary labels. Related to the points on design criteria as briefly examined in section 2.1.2, these categories of instruments fit different roles in the various phases of the technological development process (Söderholm et al, 2019). Figure 3 shows an overview of these phases, the policy instrument categories and their respective roles in this process.

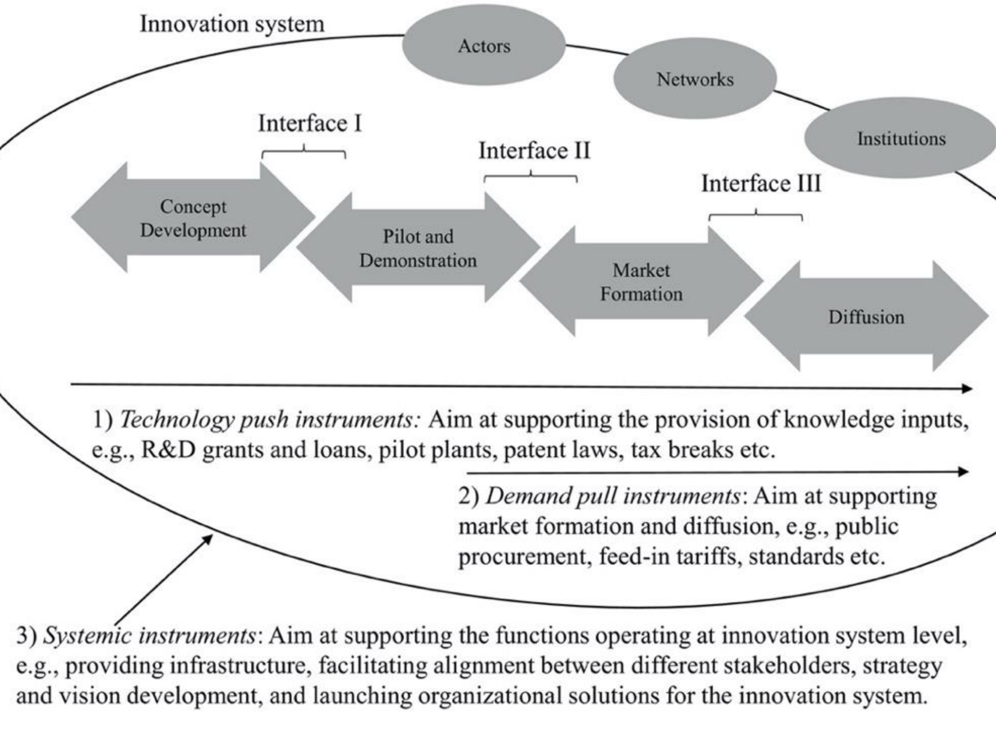

Figure 3. The role of different policy instrument mixes in progressing new technologies

Note. Reprinted from Söderholm, P., Hellsmark, H., Frishammar, J., Hansson, J., Mossberg, J., & Sandström, A. (2019). Technological development for sustainability: The role of network management in the innovation policy mix. *Technological Forecasting and Social Change*, 138, 309–323.

Bergek et al. (2008) in their TIS framework, map functional processes through a range of indicators, such as bibliometrics, number of patents, or number of graduates from relevant education programmes. Wieczorek and Hekkert (2012) instead propose assessing system functional performance through interviews with relevant actors, according to a set of diagnostic questions, which may be more fitting to a technology in its infancy, such as the electric aircraft, as its can be expected to have left few artefacts. The typology of systemic problems developed by Wieczorek and Hekkert (2012) also enhances the empirical analysis by assisting in structuring the outcomes of the coupled structural-functional analysis, as well as linking key policy issues with policy instruments. Bergek et al. (2008), however, assess the functioning of the TIS in relation to the technology's phase of development, which is due to the definition of 'functionality' differing between different phases, and thus the question of whether functionality matches the needs of that particular phase or the needs of the next phase can be raised.

Kivimaa and Kern (2016) argue that the analytical scheme of a TIS is useful for identifying problems hindering the creation and development of niche innovations, yet lacks a focus on destabilisation or destruction of regime structures, and assert that policy mixes need to attend to both processes in a mutually re-enforcing way. The authors suggest complementing the TIS framework with a set of additional analytical categories that draw explicitly on the concepts of socio-technical regime (Geels, 2002; 2004) and regime destabilisation (Turnheim & Geels, 2012). The set of regime destabilising processes Kivimaa and Kern (2016) propose, illustrated in Table 5, are (1): Control policies that put pressure on the regime and create an 'extended level playing field' for niches and incumbent technologies to compete on fair terms, e.g. by internalising externalities such as the social and environmental costs of carbon emissions. (2) Significant changes in regime rules in ways favourable to niches, allowing for reconfiguration of the institutions that favour status quo and path dependence, e.g. market reform giving priority to green technologies. (3) Reduced support for dominant regime technologies, e.g. through the removal of subsidies for fossil fuel technologies. (4) Changes in social networks, replacement of key actors, by deliberately breaking up established actor-network structures and developing different fora for interaction to bypass traditional policy networks (Kivimaa & Kern, 2016).

Table 5. Regime destabilising processes and policy instruments

Destruction (regime destabilisation)	**Description of policy instruments**
Control policies (D1)	Policies, such as taxes, import restrictions, and regulations. Control policies, for example, may include using carbon trading, pollution taxes or road pricing to put economic pressure on current regimes. Banning certain technologies is the strongest form of regulatory pressure (e.g. phase out of fluorescent light bulbs).
Significant changes in regime rules (D2)	Policies constituting, for example, structural reforms in legislation or significant new overarching laws. Historic examples of major rule changes include the privatisation and liberalisation of electricity markets in the 1990s which completely changed the selection environment within which utilities were operating.
Reduced support for dominant regime technologies (D3)	Withdrawing support for selected technologies (e.g. cutting R&D funding, removing subsidies for fossil fuel production or removing tax deductions for private motor transport).
Changes in social networks, replacement of key actors (D4)	Balancing involvement of incumbents for example in policy advisory councils with niche actors; formation of new organisations or networks to take on tasks linked to system change.

Note: Adapted from Kivimaa and Kern Kivimaa, P., & Kern, F. (2016). Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. *Research Policy*, *45*, 205–217.

The argument for focusing on changes in rules, technologies and actor-networks is as follows: technological regimes are conceptualised as concerning rules, meaning the cognitive and normative framework which is connected to functional relationships between components and actors (Kivimaa & Kern, 2016). Both the technology and the rules in the regime are path dependent and therefore difficult to change. The struggle between niches and regimes transpires around dimensions such as markets, regulations and infrastructures, and the politics surrounding them, and are enacted by actors that build coalitions as they navigate transitions. This struggle occurs particularly after the disruptive innovation has emerged and goes on until a new dominant design has emerged from competition between actors. The selection of the new dominant design both leads to and is supported by the build-up of standards, as well as optimised organisational processes around it. As such, the concept of regimes implies that the main components that can enforce stability, or when they change, create instability, are rules, technologies, and actor-networks (Kivimaa & Kern, 2016).

While the literature on socio-technical transitions points to the merit of Kivimaa and Kern's (2016) claim that there is a need to focus on both niche support and regime destruction, there are some aspects of their framework that could be further built upon. The authors conceptualise the set of regime destabilising policies as functions, which seems problematic, as the functions in the TIS literature are defined as the processes that are important for innovation systems to perform well (Wieczorek & Hekkert, 2012). Control policies hardly fit into that description. Moreover, by re-conceptualising these they could be better integrated into the TIS framework. *Significant changes in regime rules* implies that the rules favour the regime rather than the focal TIS, which can be regarded as a capacity-related institutional problem (Wieczorek & Hekkert, 2012), which may affect several functions. For example, stringent institutional problems may result in the so-called appropriability trap and favour incumbents, limiting knowledge diffusion, while weak institutional problems may hinder innovation by e.g. insufficiently supporting new technologies or developments, hampering *knowledge development* (Klein-Woolthuis, Lankhuizen & Gilsing, 2005).

According to Kivimaa and Kern (2016) *control policies* "have a clear dual function in destabilising the current regime, often by controlling the environmental impacts, while at the same time supporting niche development through creating markets for niche innovations" (p. 214). Rather than a process, control policies entail a set of policies aimed at addressing a presence-related institutional problem (Wieczorek & Hekkert, 2012), e.g. the absence of internalisation of environmental externalities hampering *market formation*. *Reduced support for dominant regime technologies* can be related to presence-related financial infrastructure problems (Wieczorek & Hekkert, 2012), whereby e.g. R&D funding is directed toward regimes rather than niches, hampering *knowledge development. Changes in social networks, replacement of key actors* implies that the existence of presence- or quality-related interaction problems (Wieczorek & Hekkert, 2012). It could be that actors are wrongly guided by stronger actors and fail to supply each other with the required knowledge, which may be caused by myopia, meaning that there is an internal orientation favouring the incumbent set-up which blocks the necessity to open up to external forces, and thus hampering *guidance of the search* or *knowledge diffusion* (Wieczorek & Hekkert, 2012).

Further, Kivimaa and Kern (2016) complement the niche creating TIS functions with the function *price-performance improvements.* According to the authors, sustainable innovations can seldom compete within normal selection environments due to a comparably weaker performance or higher price. With policies such as deployment and demonstration subsidies which enable learning-by-doing, or R&D support which lead to cost reductions through learning, price-performance improvements can be achieved and niches can over time compete with incumbent technologies (Kivimaa & Kern, 2016). However, *price-performance* improvements seem to already be captured within other TIS functions. For example, Hekkert et al (2007) argue that the function *market formation* is important for new technology because it is often difficult to compete with embedded technologies, as they offer small or perhaps no advantages at all. For that reason, it is important to create protected spaces for new technologies, and one such possibility is the creation of competitive advantage by favourable tax regimes or minimal consumption quotas. Hekkert et al (2007) further argue that R&D and knowledge development are prerequisites within the innovation system, and learning-by-doing as well as learning-by-searching are thus captured within the function *knowledge development*, which can be targeted by R&D support.

Thus, while the TIS framework does not explicitly address regime destabilisation, there is room to do so. Karakaya, Nuur and Assbring (2018) provide a helpful illustration of how the TIS and MLP frameworks relate to each other, see

Figure 4. Building on the work of Bergek, Hekkert, Jacobsson, Markard, Sandén and Truffer (2015), the authors argue that a focal TIS interacts with one or more socio-technical regimes, is influenced by landscape developments, and interlinks with other contexts such as other TISs, relevant sectors, geographical contextual structures and the political context (Karakaya, Nuur & Assbring, 2018). These contexts are defined as influences that impact the development of a TIS, but which are not affected by TIS-internal processes (Bergek et al, 2015). Depending on the purpose of the study, focus can be directed on a particular context structure to investigate its dynamics and links to the focal TIS (Bergek et al, 2015).

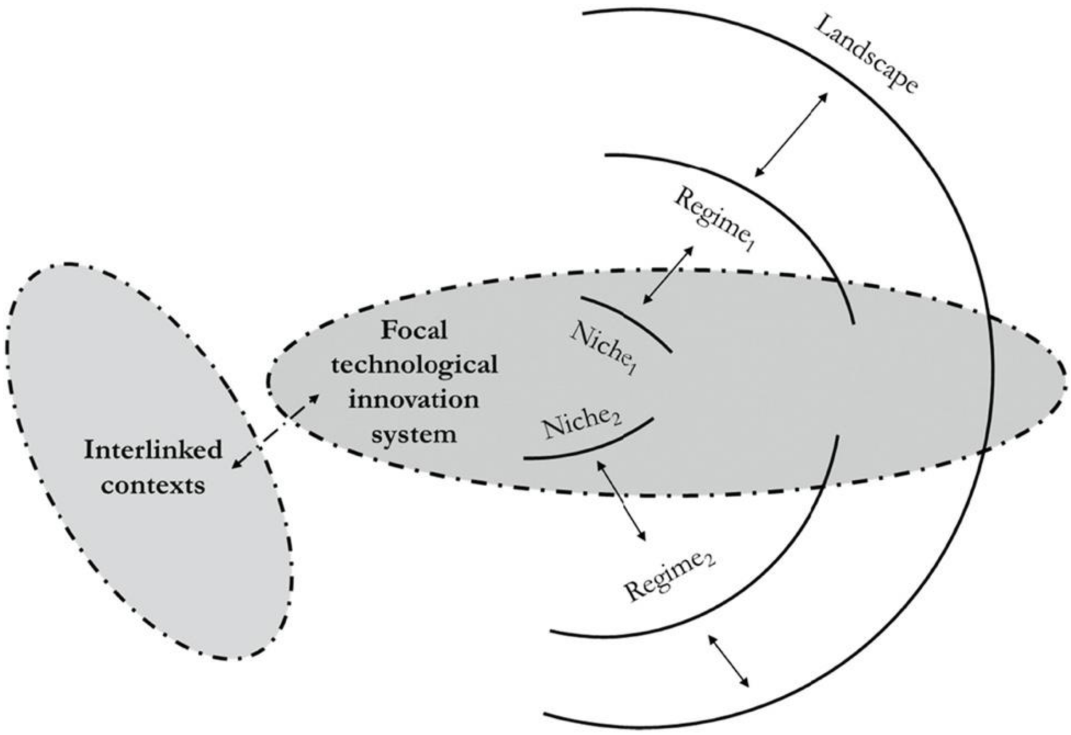

Figure 4. Interactions between the conceptual elements in a technological innovation system and the multi-level perspective.
Note: Reprinted from Karakaya, E., Nuur, C., & Assbring, L. (2018). Potential transitions in the iron and steel industry in Sweden: Towards a hydrogen-based future? *Journal of Cleaner Production*, 195, 651–663.

What is termed sector in the TIS literature closely corresponds to the concept of socio-technical regime from the MLP literature (Bergek et al, 2015), and it can therefore be studied as a particular context structure. According to Bergek et al (2015) previous TIS literature has primarily emphasised incumbents' active resistance to change, but the authors argue that it is more complex than that. Bergek et al (2015) elaborate with regard to actors, how incumbent users may participate in the development of specific technologies by defining their needs or co-creating solutions to meet those needs, and such "lead users" may thus influence *guidance of the search* within a TIS. Incumbent users may also obstruct the development of an emerging TIS by blocking *access to resources* or *de-legitimising* it. Sector-level networks (corresponding to Wieczorek and Hekkert's (2012) *interactions)* such as lobbying organisations or collaborative research networks, can influence *legitimacy creation* and *guidance of the search* of all TISs associated with the sector. If actors of a focal TIS participate in such networks, they may potentially influence agendas to the benefit of the TIS, for example by ensuring that part of the budget of a research institute is directed to TIS-relevant research. Shared technological assets (corresponding to

Wieczorek and Hekkert's (2012) *infrastructure)*, such as physical infrastructure or joint sectoral knowledge bases tend to have been shaped to serve established technologies and may therefore influence the initial *guidance of the search* of emerging TISs. Interactions also occur between a focal TIS and sector-level institutions. Sector-level policies may influence framework conditions which open or close markets for new technologies, impacting *market formation,* or affect strategies of incumbent actors in terms of emerging technologies, influencing *guidance of the search.* Sector-level institutions such as laws, regulations and economic support systems aimed at technologies in a sector, such as performance standards, may have technology-specific components or rules, affecting *market formation* and *guidance of the search* to or from specific TISs. Norms and values at the sectoral levels, such as user preferences and practices or dominant sectoral discourses, may also influence individual TISs, especially in terms of *legitimacy creation*, but these may in turn be challenged through legitimising activities stemming from a TIS (Bergek et al, 2015).

2.3.1 Framework Synthesis

Wieczorek and Hekkert (2012) provide a framework which aids in the identification of structural problems affecting an emerging TIS, such as electric aviation, as well as policy instruments to address these problems. By incorporating insights from Bergek et al. (2008), however, the functioning of the TIS can be assessed in relation to the technology's phase of development, and by incorporating insights from Bergek et al (2015), the interrelated regime context may be included in the analysis by extending the structural elements to encompass the incumbent aviation regime. The different policy instrument types; economic, regulatory, or informative instruments, overviewed in section 2.1.1, can be used in various configurations to achieve certain purposes. Here the purpose is to aid in the *creation* of sustainable innovations and socio-technical systems, which involves the use of supply push, demand pull and systemic instruments. The purpose is also to aid in upscaling that innovation through the *destruction* of unsustainable innovations and socio-technical regimes, involving the introduction of control policies, the removal of support policies for regime technology, and systemic changes to networks and regime rules, as suggested by Kivimaa and Kern (2016). As such, the expected outcome of combining these insights is a thorough identification problems (or barriers) to the development and diffusion of electric aviation, which can be addressed via policy intervention through instruments that target both innovation facilitation and regime destabilisation. To the best of the author's knowledge, this is the first study aiming to analyse a TIS together with its interrelated regime context structure.

2.4 Review of Previous Studies

As mentioned in the introductory chapter, no publicly accessible peer-reviewed literature addressing the issue on how to facilitate the development and diffusion of electric aviation exist, either in Sweden or in any other context. There are however numerous studies on innovation policy for specific technologies, employing a wide array of conceptual frameworks and methodologies, as indicated in the previous sections. There are very few studies on innovation in air transportation in general (Caetano, & Alves, 2019), two studies were however found that come to closest to the topic of this thesis, and which could provide sector-specific insights. The first study provides a historical perspective on aviation transitions, and the other models the biofuel adoption process to identify mechanisms that could be targeted by policy intervention. Finally, several studies have applied the TIS framework on eco-innovations in Sweden and in other contexts, and these may provide insights on recurring themes, as well as system-external structures which may affect a Swedish TIS.

Geels (2006) used the transformation of aviation systems and the shift from propeller to turbojet as a case to illustrate how co-evolutionary dynamics[7] play a role in socio-technical transitions. Geels (2006) found that jet engine niches were formed through co-construction and alignment of heterogeneous elements, which built up internal momentum at a moment when a major landscape change was unfolding; the approach of war. This created a window of opportunity as the higher speed of turbojets was identified as a valuable asset for fighter aircraft, and the government therefore increased R&D funding for the jet engine, leading to a proliferation of turbojet projects. Several adaptations were made in the aviation regime, such as longer runways and new aircraft control methods, and a growing commercial market saw passengers demand more comfort and less turbulence, and regime actors started jockeying for position in strategic games. These developments created another window of opportunity and further enabled turbojets to displace piston propeller aircraft. Geels (2006) findings indicate that socio-technical transitions come about when co-evolutionary dynamics at different levels align and link up, which points to the importance of timing in policy interventions to spur innovations and transitions.

Kim, Lee and Ahn (2019) utilised the multi-level perspective to develop a causal loop model that mapped out the key mechanisms and interactions affecting the adoption process of aviation biofuel, using a range of secondary sources, such as case studies and life-cycle analyses. At the macro-level, the authors found two key landscape pressures that threaten to destabilise the regime: increasing fuel cost and international pressure for emissions reduction. At the meso-level, the authors found that airports are heavily invested in existing infrastructure which is optimised for using Jet-A (conventional jet fuel), and although the introduction of biofuels requires minimal infrastructural changes, they have little incentive to drive development. Similarly, airlines are heavily invested in existing aircraft optimised for utilising Jet-A, and although airlines would be the first beneficiaries should biofuels become readily available, the high cost of biofuels leads airlines to consider them financially infeasible. Neither the airlines nor biofuel producers were found to be able to initiate the growth of the aviation biofuel market on their own. Instead the authors suggest that this lock-in mechanism be broken through two ways: the government could provide direct funds in subsidising the market price or it could funnel emission–surcharges from the use of fossil fuels to subsidise the biofuel market price. According to the authors, countries that funnelled emission surcharges to subsidise biofuels had shown most success. At the micro-level, there is an innovation push from niche level which allows the break of jet fuel's lock-in effect initiated by airlines which have begun to recognise the need for biofuels as a means of addressing their long-term environmental impact and energy security. The government, which is mainly interested in the environmental sustainability aspects, can either fund the capital flow of niche and/or directly subsidise the biofuel market (Kim, Lee & Ahn, 2019).

In modelling scenarios for the future of aviation biofuel, Kim, Lee and Ahn (2019) found that ideally the lock-in effects of current regimes are first broken by market de-risking from the government via aggressive investments in niche use, followed by market incentives rewarding biofuel use in commercial aviation (Kim, Lee & Ahn, 2019). The R&D pathway was in a best-case scenario also shaped by government intervention, with the development of an open and public form of niche clusters. The benefit of such intervention would be that two key barriers could be overcome. First, it reduces the burden on smaller firms that are unable to invest in R&D, allowing them to focus on the application of knowledge solely. Secondly, it reduces the uncertainty surrounding the costs and benefits of different pathways, which would result in the

[7] Co-evolution is conceptualised as relatively autonomous 'streams' of development in niches, regime and the landscape that influence each other (Geels, 2006).

elimination of inferior paths as well as increased investments into niche R&D and market infrastructure of more promising pathways (Kim, Lee & Ahn, 2019). Kim, Lee and Ahn (2019) also suggest that the government should enable the articulation of social demand, as a well-articulated public demand can accelerate innovation. The government should do so by nurturing science clusters that scientifically prove the impact of aviation on the environment, as well as diffuse this information to the public (Kim, Lee & Ahn, 2019). Due to the variability in lifecycle CO2 emissions between different biofuels, the authors go on to suggest that a standardised certification process is introduced which grades the level of CO2 savings of a particular biofuel, accounting for its production process and feedstock type. A related recommendation the authors make is the development of a universal biofuel environmental certification, which would reduce the uncertainty and confusion biofuel suppliers currently experience surrounding which certification to benchmark their R&D against and optimise their efforts. A key limitation to Kim, Lee and Ahn's (2019) study is the reliance on historical data, which is rather scarce for biofuels, and virtually non-existent for battery-electric aviation, why a systems dynamic model may only be a useful for electric aviation further in the future.

The TIS framework has been applied to analyse a number of different technologies, such as photovoltaics (Esmailzadeh, Noori, Aliahmadi, Nouralizadeh & Bogers, 2020), biofuels (Suurs, & Hekkert, 2009), wastewater treatment (Binz, Truffer, Li, Shi, & Lu, 2012), mobile health (van der Merwe, Grobbelaar, & Bam (2020), and most prominently offshore wind power (Reichardt, Negro, Rogge, & Hekkert, 2016; Sawulski, Gałczyński, & Zajdler, 2019; van der Loos, Negro, & Hekkert, 2020; Wieczorek, Negro, Harmsen, Heimeriks, Luo, & Hekkert, 2013).

In 2014, the Swedish Energy Agency applied Bergek et al. (2008) TIS framework to analyse five eco-innovations at different stages of development in Sweden: offshore wind power, marine energy, solar cells, electrified heavy vehicles and biorefineries (ER 2014:23). An observation the agency made was that it was not possible to find a general pattern for what system weaknesses affect the different functions, there were however some general themes, (1) the functions *knowledge development* and *knowledge diffusion* were generally hindered by deficiencies in collaboration within the value chain and between authorities; (2) *resource mobilisation* generally suffered from deficiencies in collaboration and coordination between public actors, taking the form of an absence of regulations to coordinate investments, a lack of coordination of individual research grants, and fragmentation of the supply of resources between municipalities and county councils – which was made clear when a technology area moved from one phase to another, especially from a demonstration phase to a niche market phase, (3) both the functions *guidance of the search* and *market formation* were affected by weak economic market incentives, and common to all TISs was that the primary policy instruments employed were technology-neutral instruments, which focus on the lowest possible short-term cost and spread of already established technologies.

In addition to technology- and sector-specific contextual structures, there are also institutions at the national level that affect several (or even all) sectors of a country (ER 2014:23), and these may be relevant to the Swedish electric aviation TIS as well. All TISs analysed in the report were adversely affected by the dominant notion that technology-neutral instruments are superior to more technology-specific instruments. The analyses also showed how permit rules and processes that are general for several different types of operations in a country (e.g. building permit legislation and rules for environmental permit testing) affect individual TISs. Similarly, environmental legislation (e.g. emission requirements) had a cross-sectoral impact. In addition, resource mobilisation in individual TISs were affected by overall national structures such as the financial system and the education system. For example, the lack of venture capital for major investments was highlighted in the case of offshore wind power, advanced biorefineries and solar cells and the importance of the education system being able to meet the demand for new skills was emphasised in the same three cases (ER 2014:23). Although the TISs showed common themes and are affected by similar system-external structures, the agency found that each TIS has its own, technology-specific logic and depending on the development phase a technology is in, different instruments are a good fit. As there usually are a number of system weaknesses, several policy instruments may be needed that complement each other, and therefore policy intervention needs to be multidimensional, coordinated and adapted to the specific logic and development phase of each system (ER 2014:23).

3 Methodology and Methods

In this chapter the overall research process is presented. Section 3.1 presents the research approach and the associated scientific positioning. Section 3.2 begins by detailing the scope and delimitations and goes on to discuss their implications. Section 3.3. presents the methods used to collect data and materials collected, as well as the materials used to process information. Finally, section 3.6 scrutinises the reliability and validity of the research.

3.1 Research Approach and Design

The thesis aim follows the characteristics of policy research, which is defined as "the process of conducting research on, or analysis of, a fundamental social problem in order to provide policymakers with pragmatic, action-oriented recommendations for alleviating the problem' (Majchrzak, 1984, p. 3). Policy research is thus typically framed as problem-oriented rather than concerned with theory development, and the problems are seen as occurring in a specific context, which needs to be taken into account in the analysis (Fischer, Miller, & Sidney, 2007). For this reason, contextually sensitive methods are considered to produce better recommendations, as such findings and inferences are interpretable, in that they can plausibly be defended (Collier, Brady & Seawright, 2004). The systems approach highlights the importance of understanding contextual factors by investigating relationships, and thereby discovering how something works by its effects on what surrounds it (Reynolds & Holwell, 2020). Systems thinking underlies the systems approach and is a way of looking at and making sense of the world. It is based on the assumption that if one considers a situation as a whole, properties can be observed which cannot be found from simply analysing the properties of the component parts. Systems *might* exist as actual real-world entities, but all we can *know* is what we can learn through our senses and mental operations, and therefore this view makes it difficult to claim anything definite about the ontological status of systems (Olsson & Sjöstedt, 2004). However, systems are, more definitely, conceptual constructs for inquiry into real world entities (Reynolds & Holwell, 2020), and a systems approach therefore represents a constructivist view of knowledge (Olsson & Sjöstedt, 2004). The constructivist view is reflected in the methods and methodology chosen in this thesis, which demonstrate an interpretation of the scientific theory by the author.

In this thesis, the focus was on how the Swedish state could contribute to the development and diffusion of the electric aircraft. As the research is entirely novel, it started in an exploratory manner, employing inductive strategies in order to understand the problem area and identify theoretical constructs which could help to refine the problem definition and conceptually guide the research. The theory base served as a model for assessing the functioning of the innovation system, identifying system problems, the structural causes underlying those problems, and proposing policy instruments to address them. A deductive logic was used when identifying system problems, while a retroductive logic was used to locate the underlying structures responsible for producing the observed phenomena, using creative imagination and analogy to work back from data to a causal explanation when structures were not directly observable (Blaikie & Priest, 2019).

Due to the shortcomings of TIS literature, an interdisciplinary approach was taken to this research, which implies that concepts or ideas from more than one academic discipline are used and combined in order to achieve a specified research objective (Shmelev & Shmeleva, 2012). Such an approach seems particularly suitable to apply in aiming to solve problems such as climate change and socio-technical transitions, that are associated with several, interlinked challenges. In particular, this thesis draws on insights from the literature on socio-technical transitions, and specifically the concepts of socio-technical regime and regime destabilisation, associated with the multi-level perspective to complement the TIS framework.

Following Wieczorek and Hekkert (2012) the first stage of the analysis mapped the structural dimensions of the innovation system: actors, institutions, interactions and infrastructures, as well as their capabilities. Following Bergek et al (2015), the structural dimensions of the socio-technical aviation regime were mapped as well. Departing from the work by Bergek et al. (2008), the technology phase of development was then defined in order to understand the current and next phase of the innovation in order to assess the functional performance against a goal for the system. In line with Wieczorek and Hekkert (2012), a functional analysis was performed to assess the functional performance of the system, against the previously defined goals for the system, which provided an identification of perceived problems that hinder the development of the system, as well as their structural causes. These steps provided answers to the first sub-question: *What are the barriers to the development and diffusion of electric aviation in Sweden?*. In keeping with Wieczorek and Hekkert (2012), a structural-functional analysis was performed, whereby functions were studied through the perspective of the structural elements to understand the underlying causes of identified problems. Thereby the second sub-question could be answered: *What are the underlying causes of these barriers?*. Finally, following Wieczorek and Hekkert (2012), and Kivimaa and Kern (2016), the problems were linked to TIS creating instrument goals as well as regime destabilising instrument goals, and coupled with specific policy instruments suggested by these authors as well as by interview participants, thereby providing answers to the third sub-question *How can these barriers and their underlying causes be addressed through policy intervention?*. In each stage, the methods were adjusted to the specificity of this case: a technology is a very early stage of development which is situated in a specific regime context in Sweden – a TIS and its interrelated regime context.

3.2 Scope and Delimitations

Any systems analysis, including TIS analysis requires the definition of system boundaries to distinguish it from other systems in an environment (Olsson & Sjöstedt, 2004). For the purpose of this research, the focus was on policy instruments the Swedish government could implement in order for the innovation of electric aircraft to develop and diffuse, with the aim to inform governmental decisions on this issue. The main spatial boundary was therefore defined as pertaining to activities inside Sweden. However, Sweden shares strong ties with its Nordic neighbours, is a Member State of the European Union (EU) and is governed by international law - aspects that need to be taken into account as well.

A TIS analysis captures the state of a specific innovation system in a defined moment of time (Wieczorek & Hekkert, 2012). The interviews were conducted between March 20 and April 28, 2020, which is the moment in time this study primarily captures. The mapping of structural elements includes sources which date to earlier than the beginning of the interview period and the temporal scope is thus widened. As Suurs (2009) posits, the delineation of a TIS is a complex issue, as complex systems are usually open systems, meaning that they can interact with their environment. Edquist (2004) proposes that a TIS consists of anything relevant for the development of a particular technology, however Suurs (2009) argues that such a concept would "effectively denote the universe and related matters." (p. 40). Similarly, if one were to include aspects only directly influencing a TIS, important factors such as governments, financers, etc. may be excluded. Instead the author proposes that the boundaries be drawn according to the specific purpose of an analysis.

The purpose of this analysis was to assess a TIS together with its interrelated context structures. As the TIS is an emerging technology, interviews with experts form the main source of data. For that reason, an initial boundary was drawn, but kept open for additional insights stemming from the interviews. The TIS system boundary in terms of the focal technology was defined as the ES-19 aircraft being developed by Heart Aerospace, which is a third-generation electric aircraft intended for regional aviation. There are two other electric aircraft developers in

Sweden. Blackwing which develops the two-seat light sports aircraft BW 600FG and BW 600RG (Blackwing, n.d.), and Katla Aero which develops a cargo aircraft, Katla UAV and personal passenger aircraft, Katla Aircraft (Katla, n.d. 2020). However, several projects have been initiated which centre around the Heart Aerospace's ES-19, which aids in the delineation of other system boundaries. The ES-19 could also replace several exiting passenger routes in Sweden and could therefore be considered more disruptive to the current aviation regime. It should be noted however that the developments of the different types of electric aircraft are tied, and they cannot be fully differentiated from each other. Although an electric aircraft constitutes a bundle of several technologies, it will in this thesis be regarded as one technology.

The initial system boundary in terms of actors was delineated around those who are involved in the projects which have been initiated around the ES-19: Green Flyway, NEA, and Elise wherein suppliers, users, infrastructure-related agents, government, and incumbent actors are part. The boundary was also expanded to those actors who could be considered to be part of the regime, which was delineated according to the innovation system mapping conducted by Innovair, which is Sweden's national strategic innovation programme for aeronautics (Vinnova, 2017). Upon consultation with Transport Analysis this boundary was broadened, as they had conducted a similar mapping a few years prior (Trafa, 2016:4). The system boundary concerning interactions were delineated to include those which Heart Aerospace is part of, and the regime interactions were delineated according to the mappings of Transport Analysis and Innovair (Trafa, 2016:4; Vinnova, 2017). The institutional boundary was drawn around those institutions which affect electric aviation and the incumbent aviation regime, and the infrastructural boundary was similarly drawn around the infrastructures seen as important for electric aviation and the incumbent aviation regime.

3.3 Data Collection and Analysis

3.3.1 Data Collection Methods and Materials Collected

Following the TIS framework developed by Wieczorek and Hekkert (2012), the study used mixed methods to collect and analyse data. A variety of methods were used to collect qualitative data. The initial exploratory literature review examined relevant theories pertaining to *public policy*, *innovation policy, innovation systems* and *socio-technical transitions*. The subsequent literature review targeted the mapping of structural components. Relevant literature was retrieved from a variety of academic databases, including GoogleScholar, ScienceDirect and Scopus. In addition to peer-reviewed literature, grey literature was examined and included books, reports, newspapers, working papers, company websites and reports, presentations, and government documents.

Semi-structured interviews were used to elicit knowledge on structural components which were not readily apparent from the literature, and to inform the functional analysis, as well as to provide suggestions on policy instruments. A semi-structured interview format was deemed suitable as it would allow for new ideas to be brought up and developed, as well as to grasp the interviewees subjective meanings, while still providing reliable and comparable qualitative data (Blaikie & Priest, 2019). Although there are TIS analyses which rely more heavily on quantitative data (see e.g. Bergek et al, 2008), an emerging innovation system like the Swedish electric aviation TIS can be expected to have left few artefacts, why qualitative methods were considered most suitable. Interview participants were identified through judgement and purposive sampling via actor mapping which was based on the projects they were involved in, with the ambition to capture a breadth of actor types. The snowballing sampling method was also employed, however, the people that were referred to had in each case been identified and contacted already. Finally, 14 participants were interviewed, representing suppliers, government officials, researchers, project leads and coordinators, lobbying organisations, incumbent users and incumbent suppliers. The interviews were conducted in a semi-natural setting and the individuals reported as informants and representatives of a particular type of social actor. The interviews were held between March 20 and April 28, via Zoom or other video-conferencing tools. The interview time totalled 25 hours and the duration ranged between 20 minutes to 3 hours and 26 minutes, with the average interview time spanning 1 hour and 48 minutes. An interview guide was developed based on the diagnostic questions provided by Wieczorek and Hekkert (2012), which was complemented by questions developed by Bergek et al (2008), to capture the TIS functioning more fully. The diagnostic questions were further complemented with probing questions surrounding regime actors, interactions, institutions and infrastructures. Additionally, interviewees were asked for any additional barriers that had not been captured in the interview, whether there were any policy instruments they saw fit to rectify identified problems and barriers, as well as questions tailored to the specific actor type particularly pertaining to the structural components.

Nine participants were deemed sufficiently knowledgeable about the TIS to produce meaningful results for conducting the full functional analysis through diagnostic questions. These actors were informed of the interview procedure before-hand and were provided with a visual rating scales to aid in the evaluation of the functions' performance. A 5-tier Likert rating scales of absent-weak-moderate-strong-excellent was used and constituted the sole quantitative method in this thesis, which mainly served as a framing tool to aid in discussion. All interviews were held in Swedish, but a translated sample version of the interview guide can be found in Appendix B: Sample Interview Guide. Five participants were interviewed without departing from the full diagnostic framework, and questions were instead tailored to their actor type in order to grasp the perspective and experience from their respective roles, such as capturing potential users' belief in growth potential, and underlying reasons for incumbents' resistance to change. With permission from the participants the interviews were recorded in order to allow for transcription. A full list of interview participants is found in Appendix C: Primary Data Sources, with the first nine being participants interviewed with the full diagnostic framework and the remaining five without.

Through the government agency, the author was invited to join an event on electric aviation hosted at Bromma Airport on February 11, as well as to observe interviews held between the agency and different sets of actors. Due to technical difficulties, only one of these interviews, held on April 3, could be used for data collection, which provided insight to the regime-political dynamics. These unstructured observations were recorded via hand-written notes. Finally, one actor complemented their interview and provided a more in-depth written statement regarding their view on policy instruments, which was included in the analysis. A list detailing these supplementary sources can be found in Appendix C: Primary Data Sources

3.3.2 Materials Used to Process Information

In a first step, data collected from the literature review was put into a synthesis matrix in order to map out the structural components of the TIS and regime structure, following the categories and format suggested in Table 2. In a second step, codes were created in the data analysis software NVivo as (1) structural components: actors, interactions, institutions, infrastructure; (2) their presence and/or properties; presence, capacity, quality... (3) functions: F1 Entrepreneurial activities, F2 Knowledge development... F7 Legitimacy creation: (4) evaluations of functions' performance: F1E, F2K... F7L; and (5) policy instruments.

In a next step, the transcribed interview material was imported to NVivo, where all data was coded according to the coding structure. The structural components were added to the synthesis matrix to be used in the structural mapping, as well as kept in the NVivo database for subsequent steps of analysis. After that the functional analysis was performed through collecting and synthesising the findings of each function in turn. This step also involved coding the structural elements linked to causing the identified problems, as well as linking them to their presence and/or properties. After that, coding stripes were used to highlight relationships among problems, structural elements and their presence/properties, which enabled the identification of system problems. The identified problems were analysed from a policy perspective, and if problems were seen as pertaining to a firm perspective these were omitted before collecting the findings in a synthesis matrix, which was a combined version of Table 3. Systemic problems based on functional-structural analysis of an innovation system and Table 4. Systemic problems linked to systemic instrument goals and examples of individual instruments. The problems and their structural causes were then matched with the policy instruments suggested by the interview participants, Wiezcorek and Hekkert (2012), as well as Kivimaa and Kern (2016) which were seen as able to address the identified problems. Subsequently, the material from the previous step was analysed to identify key policy issues. Finally, using an iterative approach, preliminary results from the final analysis step were carried back to previous stages and used there to further develop and clarify the analysis.

3.4 Validity and Reliability

Making claims based on the findings of contextual policy research is challenging due to the lack of tropes or accepted language of reliability and validity available to the researcher (Clarke, 2007). In a radical constructivist view 'objectivity' in the traditional sense cannot be claimed, and instead the criterion by which to judge the results "must be related to how well it serves the purpose of the study, what use can be made of it and whether, and to what extent, the knowledge works" (Olsson & Sjöstedt, 2004, p. 21). The value of the results can thus be judged by the extent to which they are adequate in the contexts in which they were created, which in the radical constructivist view is called the 'viability' criterion (von Glasersfeld, 1995).

Moving further toward objectivism on the epistemological continuum and away from a complete rejection of epistemic justificationism, one can still speak in terms of reliability and validity. Research validity relates to the quality and soundness of the findings and can be divided into internal and external validity (Seale, 1999). Internal validity concerns "the extent to which causal propositions are supported in a study of a particular setting." (Seale, 1999, p. 38). Maxwell (2004) suggests using strategies for assessing causal claims, such as searching for discrepancies or disconfirming evidence, triangulation of different sources of information, different investigators, or different methods of data collection, and feedback on interpretations from participants themselves. All except for one of the strategies, making use of different investigators, were employed in this thesis. External validity concerns "the extent to which causal propositions are likely to hold true in other settings, an aspect of the generalizability of findings." (Seale, 1999, p. 40). As the findings in this research are context-dependent they cannot be generalised without considering the context. The findings could however provide empirical evidence in favour or against established theory and findings, and could for example challenge the current understanding of the structural causes of TIS problems.

Reliability concerns the degree to which other researchers applying similar constructs would match these to data in the same way as the original researcher, and the replicability of entire studies (Seale, 1999). The strategies employed to achieve higher reliability include providing a rationale for the sampling procedure, deploying different data collection instruments, and employing a systematic procedure for and thoroughly documenting data collection and analysis (Sadovnik, 2007). While the suggested strategies have been pursued, the replicability of this research depends on the context of future inquiries, and as the results provide a snapshot of the TIS functioning at a specific moment in time, the contextual factors are likely to have changed. Furthermore, Blaikie and Priest (2019) argue that the character of qualitative data makes corroboration and replication more difficult, as the qualitative researcher is usually the measuring instrument and no two instruments are the same.

4 Results and Analysis

In this chapter the results from the analyses are presented. Section 4.2. maps the structural elements of the TIS and the regime context. Section 4.3. then determines the current and next stage of technology development. Section 4.4. presents the functional analysis, which details the problems and structural causes of these problems as reported by interview participants. Section 4.5. presents the results of the structural-functional analysis where the underlying causal mechanisms of these problems and associated structural causes have been determined and presented according to their structural category. Finally, section 4.6. presents a set of key policy issues which are deemed to hinder the Swedish electric aviation TIS.

4.1 Structural Mapping

4.1.1 Actors

Actors relevant to a TIS include civil society; companies such as start-ups and multinational corporations; knowledge institutes such as universities, research centres, and schools; government; NGOs; and other parties such as legal organisations, financial organisations, intermediaries, knowledge brokers, and consultants (Wieczorek & Hekkert, 2012) .

Companies

The supply-side company actors which are part of the TIS include Heart Aerospace, which is a Swedish start-up that aims to deliver the first ES-19 electric airliner certified for commercial flight by 2025 (Heart Aerospace, n.d.). The aircraft will take 19 passengers and have an operating range of 400 km, which is enough to cover a third of domestic traffic in Sweden, and 14 percent of departures worldwide (Wormslev, & Broberg, 2020). Heart Aerospace started as a Swedish Agency for Innovation Systems (Vinnova) project called Electric Aviation in Sweden (Elise), but was part of the accelerator programme Y Combinator in Silicon Valley where they made their first fundraising (IN1). They are now 12 employees, with half employees and half contracted consultants. The company is currently building an electric drivetrain in order to build a 400 kW class engine together with a battery pack and power electronics. Heart Aerospace is an Original Equipment Manufacturer (OEM), i.e. the company with the ultimate responsibility for the aircraft even though they cooperate with half a dozen different actors: engine manufacturers, propeller manufacturers, battery suppliers, and airframe manufacturers. The company works in an office and hangar located at Säve airport in the outskirts of Gothenburg, the electrification hub in Sweden (IN1). In the first stage of Elise, Heart Aerospace lead the concept design work which continued on to the second stage where Heart Aerospace also had a large role in the business and market development (Vinnova 2018; 2020). Heart Aerospace is also at the centre of the network Nordic Electric Aviation (NEA), and closely cooperates with the test arena initiative Green Flyway.

QRTECH is a service provider working in projects involving the development of software and hardware in automation, electrification, engines, batteries, energy converters and connectivity (IN3). The company was involved in the first stage of the Elise project working on electric system design, which Heart Aerospace and other actors have taken over development of since (IN3). Elitkomposit is a composite manufacturer and developer (Elitkomposit, n.d.) which was part of the first phase of the Elise project, in charge of creating a scale model of the aircraft in scale 1:4 (Vinnova, 2018). Abtery is a company specializing in is an electric system design (Abtery, n.d.), which was part of the first stage of Elise, and designed and developed a test rig for the electric drivetrain motor, power electronics, and battery pack (Vinnova, 2018). North Sea Drones is a drone developer (North Sea Drones, n.d.), which is building scale models for the electric aircraft during the second stage of the Elise project (Vinnova, 2020). Icarus is a company specialising in simulated flight training (Icarus Digital Math, n.d.), which is part of the second phase of the Elise project developing aerodynamics software to be used for aircraft design (Vinnova, 2020).

There are around 300 airports in Sweden, most of which are small and serve general aviation (Trafa 2016:4). Swedavia is a state-owned enterprise that operates ten of Sweden's largest airports (Swedavia, n.d.). Swedavia co-founded Fossil Free Aviation 2045 and is part of NEA (Nordic Innovation, n.d.), and Åre Östersund Airport is part of Green Flyway (Fossil Free Aviation, n.d. a). It has also launched a strategy for electric aviation with the aim that Swedavia's airports will be able to handle electric aviation and that a first commercial electric airline route can be put into use around 2025 (Swedavia, 2020). Several smaller regional airports are approaching the TIS, although they are represented by Svenska Regionala Flygplatser (SRF). The Finnish airport operator Finavia, Danish Copenhagen Airports, and Norwegian Avinor are also part of NEA (Nordic Innovation, n.d.). Companies that are not part of the TIS networks but are relevant to the TIS are electricity suppliers Ellevio, ABB, and Vattenfall, who may have started to develop knowledge surrounding the needs for electric aviation (IN8).

Demand-side companies part of the electric aviation TIS include Scandinavian Airlines System (SAS), which is the flag carrier of Sweden, Denmark and Norway. SAS carried 30 million passengers in 2018 (SAS Group, 2018), and is the largest airline in Sweden and Denmark, and is owned by SAS Group which is partially owned by Sweden and Demark, with a 14.82% and 14.24% holding respectively (SAS Group, n.d.). Braathens Regional Airlines (BRA) is a Swedish airline company owned by the holding company Braganza (Braganza, 2018). With 2 million passengers annually it is the second largest operator in the Swedish domestic market (Braganza, 2018). Following the Covid-19 pandemic, BRA applied for corporate restructuring on April 6 2020 (TT, 2020). BRA is/was part of NEA (Nordic Innovation, n.d.), and Fossil Free Aviation 2045 (Fossil Free Aviation n.d. b). The Greelandic airlines Air Greenland, Finnish Finnair, Icelandic Icelandair are also part of NEA (Nordic Innovation, n.d.).

Regime Level Companies

Saab and GKN Aerospace are according to Vinnova (2018) part of an advisory board for the first stage of the Elise project, although their involvement remains contested (IN14). Saab is a Swedish aerospace and defence company (Saab, n.d.). In the past, Saab has designed and manufactured civil aircraft and passenger cars, but now focus on military applications, although two turboprop aircraft (a smaller type of passenger aircraft) are still in use (Saab, n.d.). GKN Aerospace Sweden, formerly Volvo AB, preceding the company's acquisition by British engineering multinational conglomerate GKN, is a motor component manufacturer which also delivers entire military engine systems (IN14). Other parts of GKN deliver automotive and aerospace components, and has previously manufactured turboprop aircraft, and is still responsible for their technical support (IN14). GKN Aerospace and Saab form the backbone of Innovair, which also includes 35 small and medium sized companies (SMEs), one of which is Elitkomposit which is also part of the electric aviation TIS (Innovair, n.d. a). The airports and airlines are relevant for the regime-level as well (Innovair, n.d. b), and as are also fuel suppliers.

Industry and Interest Organisations

Svenska Regionala Flygplatser (SRF) is owned by the Swedish Regional Airport Association (SRFF), which is a cooperation body for Sweden's non-governmental airports (termed regional airports in this thesis) (Svenska Regionala Flygplatser, n.d.). SRF works to provide the conditions for non-state airports to maintain and develop their operations (Svenska Regionala Flygplatser, n.d.). SRF is part of NEA, and one of the regional airports is part of Green Flyway (IN11).

Swedish Aviation Industry Group (SAG) is part of The Swedish Confederation of Transport Enterprises, an umbrella organisation for associations and companies in the transportation sector in Sweden (The Swedish Confederation of Transport Enterprises, n.d.). SAG is a member organisation that supports the Swedish aviation industry to develop national and international business alongside developing industry knowledge networks (Swedish Aviation Group, n.d.). SAG has been involved in several lobbying activities for electric aviation, such as writing debating articles and hosting events (IN5)

Regime Level Industry and Interest Organisations

The Swedish Air Transport Society is an association which is part of, or considered to be a stakeholder to Innovair, representing the aviation industry actors Saab, GKN Aerospace, BRA, SRF, and Swedavia in Sweden (Innovair, n.d. b). It communicates ideas, opinions and knowledge about commercial aviation and the aviation industry, and has the aim to strengthen confidence in commercial aviation and aeronautics industries such that they are given opportunities to work and grow in Sweden (Innovair, n.d. b). The Swedish Security and Defence Industry Association (SOFF) is open to companies whose production of security and defence equipment and services constitutes an essential part of their output, and currently has 65 member companies including 55 SMEs (Innovair, n.d. b). The association promotes the common interests of the security and defence industry and strives for increased understanding of its importance to Swedish security and defence policy (Innovair, n.d. b).

Swedish Aerospace Industries (SAI) is a non-profit organisation for the Swedish aerospace industry that works to increase knowledge of Swedish aerospace operations, activities, and its special terms and conditions (Innovair, n.d. b). SAI aims to promote collaboration between universities, government agencies, small and large businesses, institutes and policy makers (Innovair, n.d. b). Aerospace Cluster Sweden (ACS) is a network organisation focused on small and medium-sized companies that are professionally engaged in the aerospace industry (Innovair, n.d. b). Finally, The Swedish Society for Aeronautics and Astronautics (FTF) is a non-profit and non-political organisation that works to promote aerospace engineering business in Sweden (Innovair, n.d. b).

Universities

The Royal Institute of Technology (KTH) offers education and conducts research on aerospace and aeronautical engineering technology, and contributed with aerodynamic analysis for the first stage of the Elise project and aerodynamic design for the second stage (Vinnova, 2018; 2020). Linköping Technical University (LiU) offers education and conducts research in aeronautical engineering, and contributed with concept design in the first stage of the Elise project and aerodynamic design and scale model testing in the second stage of Elise. Chalmers University of Technology offers education and conducts research in aerospace engineering and automation, and contributed in the first stage of the Elise project with aeroacoustics, and with wind tunnel testing of scale models and propeller construction in the second stage. Lund University Faculty of Engineering (LTH) offers education and conducts research in mechanical and electrical engineering. LTH contributed with research on automation in the first stage of Elise, and research in automation and air traffic management in the second stage. Uppsala University (UU) offers education and conducts research in mechanical and electrical engineering, and contributed with research on drivetrain in the first stage of Elise, and explored future technologies in the second stage (Vinnova 2018; 2020).

Regime Level Universities

Apart from the above-mentioned universities, Innovair maps out University West (HV), Blekinge Institute of Technology (BLT), Halmstad University (HH), and Mälardalen University as relevant to the aviation innovation system as well (Innovair, n.d. c.).

Schools

There are several aviation education programmes spread throughout Sweden, such as for pilots, flight attendants, flight technicians, flight mechanics and other services in the aviation industry. These programmes are publicly or privately funded and range from vocational secondary education to university college education, and include the Lund University School of Aviation, OSM Aviation Academy, and Nordic Flight Training (Flygtorget, n.d.).

Research Institutes

Research Institutes of Sweden (RISE) is a Swedish state-owned research institute which runs the innovation cluster Fossil Free Aviation 2045, and support business and marketing work and project management for NEA and Elise (IN9).

Regime Level Research Institutes

Swedish Defence Research Agency (FOI) is the largest research organisation in Sweden (Innovair, n.d. d). In the aeronautics area FOI is active in basic disciplines like aerodynamics, aeroelasticity, structures and materials, flight mechanics, and autonomy, and runs an air combat simulation centre for the Swedish air force. Moreover, FOI is partner in interdisciplinary research projects and in many international research cooperation projects. Swerea SICOMP is a leading research institute in the field of polymer fibre composites and works with applied composite research, development, and training, and is active in many research projects related to aeronautics and leads the establishment of the Compraser Labs arena in Linköping (Innovair, n.d. d). Finally, Swerea IVF offers advanced R&D and consulting services to the manufacturing and engineering industry. The goal is the rapid introduction of new technologies and methods to practical use in their customers' operations. Swerea IVF is active in many research projects related to aeronautics and has the lead in the establishment of the arena Produktionstekniskt Centrum in Trollhättan (Innovair, n.d. d).

Government

The International Civil Aviation Organization (ICAO) is a United Nations (UN) body tasked with developing the principles and technology of international aviation as well as promoting the planning and development of international aviation (Trafa, 2016:4). ICAO therefore works with increasing aviation safety through common rules in, among other things, air traffic services, but also with regard to the design of airports, certification of pilots, aviation technicians, air traffic controllers, aircraft airworthiness, rules for planning, and implementation of flights (Trafa, 2016:4).

The European Commission conducts transport policy, among other things, by proposing new common legislation, but also by producing white papers for transport which indicate the direction of European transport policy (Trafa, 2016:4). In the aerospace field it has been concerned with streamlining Europe's airspace, integrating traffic types, and reducing fossil fuel dependence. Historically, the EU has been a driving force in liberalising the European aviation market (Trafa, 2016:4). The European Union Aviation Safety Agency (EASA) is an agency of the EU responsible for ensuring safety and environmental protection in civil aviation, including responsibility for certification, regulation, standardisation, and airworthiness directives for aircraft within the EU (European Union, n.d.). The national aviation authorities in the Member States are represented in a group, the Member States Advisory Body (MAB), which advises EASA on regulatory development issues and prioritisations (The Swedish Transport Agency, 2017). There are also sub-groups, Technical Bodies (TeB), where EASA can obtain advice from the various subject areas. A group with similar tasks, Stakeholders Advisory Body (SAB), is set up for representatives of the aviation industry and its organisations (The Swedish Transport Agency, 2017).

The Swedish Transport Agency is the state authority responsible for most of the regulations, supervision, permit testing and record keeping in aviation and the transport area in general in Sweden (N2017/00590/MRT). For the aviation area, this means that the agency issues operating licenses and operator licenses to airlines to conduct aviation (Trafa, 2016:4). In addition, the Swedish Transport Agency also issues certificates, permits and permissions needed to perform air traffic management services. The agency also exercises supervision of all airports in Sweden, which means that the airports are monitored to ensure that air safety is maintained and that airport fees are in accordance with the Airport Fees Act. The role of the Swedish Transport Agency within market surveillance is derived from their responsibility for market access, supervision and competitive conditions. The Swedish Transport Agency also has a responsibility for air traffic services for civil and military aviation. Furthermore, the Swedish Transport Agency assists the government in the preparation of cases in various international collaborations (Trafa, 2016:4).

The Swedish Transport Administration is responsible for all intermodal long-term infrastructure planning for road, rail, sea and air transport, as well as for the planning, building, operation and maintenance of the state roads and railways (The Swedish Government, n.d.). Contrary to road and rail, the Swedish Transport Administration does not own its aviation infrastructure, but instead produces forecasts for aviation and is responsible for road and rail connections to the airports (Trafa, 2016:4). Furthermore, the Swedish Transport Administration is responsible for the state's agreement on transport policy-motivated public transport, including air traffic, which is not maintained by any other actor and where there are no conditions for commercial operation, which is mainly between Stockholm Arlanda Airport and a number of airports in northern Sweden (Trafa, 2016:4; N2017/00590/MRT). The agency is currently carrying out a feasibility study, as part of its appropriation directions for 2020, that illustrates the extent to which the use of biofuels and electrification of procured air traffic can contribute to the goal of reducing the climate impact of aviation and increasing accessibility throughout the country (I2019/03374/US).

The Swedish Civil Aviation Administration (LFV) is a state-owned enterprise responsible for air traffic navigation services for civil and military aviation in Sweden (LFV, n.d. a). The newly developed LFV Aviation Research Center (LARC) in Örnsköldsvik focuses on digitisation and automation development, and serves as an arena for testing, demonstration and development of small and large electric aircraft (LFV, n.d. b). LFV was also part of the advisory board in the first stage of the Elise project (Vinnova, 2018).

Transport Analysis is the state authority responsible for providing policy advice within the sphere of transport, by reviewing, analysing, following up and evaluating proposed and implemented transport policy measures at the request of the Government, as well as analyses the business environment and future prospects within transport policy (Trafa, n.d.). The agency is also responsible for the production of official statistics in the transport and communication sectors (Trafa, n.d.). Transport Analysis was tasked with analysing developments regarding electric aircraft, as well as suggesting policy measures which could be suitable to promote development and a transition to a greater use of electric aircraft (Ministry of Infrastructure, 2020).

The Swedish Energy Agency is the administrative authority responsible for the use of renewable energy, improved technologies, a smarter end-use of energy, and mitigation of climate change (Innovair, n.d. e). The authority is also responsible for coordinating the transition of the transport sector away from fossil fuels, and finances R&D in the energy sector and for aviation, biofuel development is particularly relevant (Trafa, 2016:4), of which the innovation cluster Fossil Free Aviation 2045 is one such funded project (IN9).

The Swedish Agency for Innovation Systems (Vinnova) has the task of promoting sustainable growth through funding of needs-motivated research and development of effective innovation systems in Sweden (Vinnova, 2011), and by developing catalytic meeting places (Innovair, n.d. e).Vinnova funded the Elise project via its initiative challenge-driven innovation which aims to solve societal challenges that require broad cooperation to be overcome (Vinnova, n.d.).

The Swedish Environmental Protection Agency is responsible for producing national statistics on greenhouse gases and reports annually to the government, the European Commission and the UN Climate Convention (Trafa, 2016:4). The authority therefore has a central role in compiling information on the climate impact of aviation (Trafa, 2016:4). Finally, two other relevant authorities in Sweden are the Swedish Competition Authority and the Swedish Consumer Agency. The Swedish Competition Authority has the task of promoting healthy competition in Swedish markets. This could mean, for example, active action to counteract cartels and to intervene against private and public actors who abuse their dominant position in the aviation market. The Consumer Agency shall, among other things, work to protect, support and inform Swedish consumers (Trafa, 2016:4).

Regime Level Government

The Swedish Armed Forces is one of Sweden's largest authorities, and its task is to be responsible for Sweden's military defence (Innovair, n.d. e). The Swedish Air Force, part of this authority, is tasked with organising and training aircraft units as well as base and command units, and completes its tasks by means of fixed-wing aircraft and helicopters. The Swedish Defence Materiel Administration (FMV) is a civil authority which is tasked with delivering defence logistics to the key partner, the Armed Forces. As the procurement agency for defence material FMV has a key role related to aeronautics in Sweden. The Swedish Research Council for Sustainable Development (Formas) is a government agency which works to promote and support basic research and needs-driven research in the areas environment, agricultural sciences and spatial planning. Innovair considers LFV, The Swedish Transport Agency, The Swedish Energy Agency, and Vinnova to be part of the innovation system as well, and Vinnova, the Swedish Energy Agency and Formas collaborate on the venture Strategic Innovation Programmes, of which Innovair is one out of 17 (Innovair, n.d. e).

Other parties

The European Regional Development Fund (ERUF) is an EU programme which provides financial and other types of support for interregional cooperation projects (Interreg Europe, n.d.), and provided funding for Green Flyway (IN2). The Nordic Council of Ministers is the official body for inter-governmental cooperation in the Nordic Region (Norden, n.d.), which via its sub-section Nordic Innovation funded the NEA project (Nordic Innovation, n.d.).

4.1.2 Interactions

The interactions relevant to a TIS include those at the level of individual contacts as well as at the level of networks (Wieczorek & Hekkert, 2012). Fossil Free Aviation 2045 is an innovation cluster founded by SAS, RISE and Swedavia, and funded by the Swedish Energy Agency, which brings together authorities, businesses, public actors, academia and the industries, with the aim to accelerate the transition to fossil free aviation (Fossil Free Aviation, n.d. c). From the beginning the cluster focused on liquid fuels, mainly biofuels, but has as of recently decided to include electric aviation within its scope going forward (IN9).

Electric Aviation in Sweden (Elise) is a Vinnova-funded project aiming to create an electric aviation industry and infrastructure in Sweden (Vinnova, 2018). It receives funding in three stages and is currently in stage two. The first stage focused on initiation and involved the creation of a roadmap from three perspectives; international positioning, societal needs and technology inventory (Vinnova, 2018). The second stage focuses on deepening the collaboration project and involves coordinating the development and use of electric aircraft in Sweden (Vinnova, 2020). The third stage will focus on full-scale testing and implementation (VI 2017:06).

Nordic Electric Aviation (NEA) is a platform funded by Nordic Innovation, a sub-section of the Nordic Council of Ministers, where actors come together to accelerate the introduction of electric aviation in the Nordic countries (Nordic Innovation, n.d.). NEA has four overall objectives: to standardise electric air infrastructure in the Nordic countries, to develop business models for regional point-to-point connectivity between Nordic countries, to develop aircraft technology for Nordic weather conditions, and to create a platform for European and global collaboration (Nordic Innovation, n.d.).

Green Flyway is an international test arena for the development of electric aircraft, drones, airspace control of autonomous aircraft, airport infrastructure, charging infrastructure, new electric airlines and sustainable regional accessibility and growth (Green Flyway, 2020). The project is funded by The European Regional Development Fund (ERUF) and its project partners (Green Flyway, 2020). The test arena is located in the Swedish municipalities Östersund and Sveg, as well as the Norwegian municipalities Röros and Trondheim (Green Flyway, n.d.).

Finding Innovations to Accelerate Implementation of Electric Regional Aviation (FAIR) is a project which has applied for funding from ERUF, the Regional Council of Ostrobothnia and Region Västerbotten (Kvarken, n.d. a). The project aims to research new possible flight routes and the social and economic benefits of implementing them in the Kvarken region, which is an area encompassing parts of Sweden and Finland. The main objective of FAIR is to develop commercialisation models and help the region in realising them by introducing private and public sector innovations (Kvarken, n.d. a).

Regime Level Interactions

Innovair is Sweden's national strategic innovation programme for aeronautics (Innovair, n.d. f). The aim of Innovair is to coordinate and support stakeholders from industry, universities, institutes, associations and government agencies who are active in the aeronautics sector. The main objective is to promote favourable conditions for a strong aeronautics industry in Sweden and to strengthen the sector through increased collaboration, research and information dissemination. Public funding of Swedish aeronautical innovation activities is mainly funnelled through three funding programmes: National Aeronautics Research Programme (NFFP), demonstrator programmes and military research and technology (R&T) programmes. Innovair is in turn part of several international aeronautical research initiatives, such as the EU programmes Clean Sky, Horizon 2020, SESAR, GARTEUR, and AirTN. Innovair is also part of bilateral cooperation agreements with Brazil, the United Kingdom, and Germany (Innovair, n.d.f). Innovair has two production arenas which provide support and resources for SMEs so that they can establish contact with the aerospace industry, understand the industry's needs, and participate in the industry's R&D programmes (Innovair, n.d. g). The arenas also meet the need for resources to develop and verify technologies for the aerospace industry (Innovair, n.d. g).

4.1.3 Institutions

Hard institutions

The hard institutions relevant to a TIS include rules, laws, regulations, and instructions (Wieczorek & Hekkert, 2012). International aviation is governed by a complex and fragmented system of global regulatory agencies. The Chicago Convention on International Civil Aviation from 1944 forms the basis for international cooperation surrounding aviation, and for the UN-based Civil Aviation Organisation, the International Civil Aviation Organization (ICAO) which has established standards and recommendations for civil aviation in a total of 19 annexes to the convention (The Swedish Transport Agency, 2013). Among other things, demands are placed on aircraft noise characteristics and CO_2 emissions. Member States are required by international law to comply with the standards which are enforced via the national civil aviation regulations and are strongly encouraged to follow the recommendations (The Swedish Transport Agency, 2013).

Sweden as a member of the EU is obliged to follow EU regulations relating to aviation. The European Union Aviation Safety Agency (EASA) is the agency responsible for rulemaking, issuing certificates and approvals, and standardisation of national aviation authorities within the EU (The Swedish Transport Agency, 2012). EASA legislation includes aircraft certification, continuing airworthiness, operations, flight crew licensing and air traffic management (The Swedish Transport Agency, 2012). In Sweden there are, in addition to ICAO and EASA regulations, a number of regulations stemming from the Swedish Transport Agency (The Swedish Transport Agency, 2015), as well as the Aviation Act (SFS 2010:500), and the Aviation Regulation (SFS 2010:770).

Other regulations which impact aviation include The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) which came into force in 2019 and obliges airlines to offset their increase in emissions after 2020 by purchasing credits from emission mitigation projects outside the aviation sector (ICAO, 2018). Similarly, The European Union Emissions Trading System (EU ETS) obliges airlines since 2012 to purchase eligible emission units generated by projects that reduce emissions in other sectors to offset aviation emissions of flights where both takeoff and landing are within the EU (EU, 2017). In 2018, Sweden introduced an aviation tax which obliges airlines with aircraft seating 10 or more passengers and departing from Swedish airports to pay a rate between SEK 62 to SEK 260 per passenger depending on the distance to the final destination (SFS 2017:1200; SFS 2019:685). Apart from the aviation tax, there are a number of government fees such as for permit testing, supervision and record keeping (TSG 2015-2093). There are also a number of airport charges that airlines are obliged to pay, such as starting and landing fees, noise fees, and exhaust fees (TSG 2015-2093). Finally, there are several institutions that indirectly affect aviation, such as work permits, IPR laws, housing policies, and EU competition law (ER 2014:23).

Soft institutions

The soft institutions include customs, common habits, routines, established practices, traditions, ways of conduct, norms, and expectations (Wieczorek & Hekkert, 2012). Among TIS and regime actors there are a number of diverging soft institutions. Perceptions surrounding timeframes differ, with traditional aircraft development work spanning several decades, and electric aviation development only a few years (IN9). Similarly, research processes differ, with regime actors pursuing more low risk projects than TIS actors (IN4). Additionally, ways of conduct and 'languages' are considered to differ (IN9), and the level of expected political influence seem to differ as well (OB2). Soft institutions among aircraft passengers include the need to feel safe while travelling on an aircraft (IN13), expecting a certain level of comfort (IN14), and that the journey is cheap (IN9). Environmental consciousness as well as the "flygskam" trend, roughly translated to flying shame, whereby one should feel ashamed of boarding a plane because of its negative environmental impact, is growing among the general public in Sweden (IN9). Finally, it may be common to be more risk averse in Sweden than in other national contexts (IN1).

4.1.4 Infrastructure

Infrastructure encompasses physical infrastructure, such as artefacts, instruments, machines, roads, buildings, networks, and bridges; knowledge infrastructure such as expertise, know-how, strategic information, and financial infrastructure such as subsidies, financial programs and grants (Wieczorek & Hekkert, 2012). The physical infrastructure required for electric aviation include assembly and testing facilities, air traffic control system, as well as airports equipped with repair and maintenance capabilities, runways and charging infrastructure, and a connection to electricity grids (Geels, 2006; IN1; IN2). Currently the airports are equipped with fuel stations, and lack charging infrastructure (IN2). Heart Aerospace has a hangar on Säve Airports outside Gothenburg (IN1), and a test arena has been established in the Swedish municipalities Östersund and Sveg, as well as the Norwegian municipalities Röros and Trondheim (Green Flyway, n.d.). A testbed for smaller electric aircraft has also been developed in Örnsköldsvik airport in cooperation with The Swedish Civil Aviation Administration and Katla Aero[8] (IN9).

The financial infrastructure for electric aviation consists of private and public project funding. The government funding via Vinnova amounts to SEK 495 000 kronor for the first stage of Elise (Vinnova, 2018), SEK 10 million for the second stage, (Vinnova, 2020), and up to SEK 20 million for the third stage. NEA received SEK 4 million from Nordic Innovation (Nordic Innovation, n.d.; Rise, n.d.), and Green Flyway received SEK 14,2 million from the Swedish side and NOK5,5 million from the Norwegian side (Östersund, n.d.). FAIR has applied for funding and have so far received EUR 51 500 from ERUF, the Regional Council of Ostrobothnia and Region Västerbotten for a pre-study (Kvarken, n.d. b). Private funding has mainly been provided in-kind by project participants (IN1). In Sweden, 28 regional airports receive government subsidies amounting to SEK 103 million per year, and 10 air traffic routes were as of 2018 procured by the government (Trafa 2019:6). Furthermore, Innovair receives SEK75 million in government subsidies per year (375 MSEK over 2017-2022) via Vinnova (IN6).

4.2 Defining the Technology Stage of Development

There exist three generations of electric aircraft today (IN1). The first-generation electric aircraft carries two passengers and travels circa 500 km, and one such developer, Pipistrel in Slovenia, is currently working towards receiving a type certification from EASA. A second-generation aircraft has been produced in Canada and is a retrofitted seven-seater aircraft that has so far conducted a test flight. The ES-19 being developed by Heart Aerospace is a third-generation aircraft, which will be able to carry 19 passenger and fly 400 km. Heart Aerospace is currently in a concept development phase, aiming to test their drive train later this year. The next stage for the ES-19 is obtaining certification according to EASA CS-23 in order to be able to start building the aircraft by the year 2025. The next stage for the innovation electric aircraft more broadly is a construction which is larger and/or travels farther, which would constitute a fourth-generation aircraft, and can be said to be in a pre-concept development phase (IN1).

4.3 Functional Analysis

4.3.1 F1 Entrepreneurial Activities

Overall the function *entrepreneurial activities* is rated as strong (3.6). The strength of the function mainly derives from the Swedish experience within aircraft design and electrification (IN7), and

[8]An interview informing these developments had to be cancelled due to Covid-19, and thus had to be omitted from the analysis.

tight cooperation between industry, academia and government (IN8). Other driving forces for entrepreneurial experimentation are recent developments in motor and battery technology (IN2), and the fact that the standard for the electric aircraft has yet to be set globally, and with it, the opportunity to be pioneering (IN3). In Sweden, there are three initiatives concerning electric aviation, all of which are start-ups, and their entrepreneurial activity is considered to hold high quality and is regarded as an important driver for taking the innovation to the next stage of development in regards to building a fourth-generation electric aircraft (IN3, IN8). There is only one initiative, by Heart Aerospace, that develops an aircraft that could replace the flight routes that exist today. For that reason, more actors are needed according to several interviewees (IN5, IN4, IN7, IN9). The absence of entrepreneurs is thought to be related to a general risk aversion in Sweden (IN1), a lack of direction from the government (IN5), and an absence of sufficient funding (IN5, IN8). The lack of funding is thought to be related to the fact that aviation is a traditional industry which makes it difficult to attract capital (IN4), and that there is a lack of channels to attract venture capital in Sweden (IN1). It may also be related to the fact that only the two main incumbent regime supply actors as well as small and medium sized enterprises are eligible for funding in Innovair, and that start-ups thus are excluded.

In terms of developing the electric aircraft, there are no incumbent actors involved in the Swedish electric aviation TIS, although some minor experiments may have been conducted (IN4). The fact that incumbent regime supply actors are not involved is seen as positive from an entrepreneurial activity perspective as smaller actors are seen as able to work more freely, focused and faster (IN3, IN8). The Swedish or partly Swedish companies Ellevio, ABB, and Vattenfall have however started to see that this is a potential new business area and a new way to sell electricity and smart electricity solutions, and therefore they have started knowledge building (IN8).

Due to the importance of safety aspects in aviation, many rigorous tests are required (IN6, IN9, IN14). Testing is also considered to be important for creating legitimacy and reducing uncertainties regarding costs (IN2). Research at universities is usually concluded at the basic or applied research stage (TRL 3-4), which is followed by technological verification and demonstration (TRL 5-6) before product development (TRL 7-8) and verified product use can take place (TRL 9). Testing is usually performed by research institutes, acting as a link between universities and producing companies, but in Sweden the aeronautical institutes have in many areas largely been dismantled (IN6). While RISE manages Fossil Free Aviation 2045, NEA, and Elise, it has little experience in aviation and aeronautical research (IN7), and no large-scale tests on electric aviation have been performed at RISE thus far, which could be due to a lack of financial resources and ambiguous targets (IN6). As these tests can amount in the order of SEK500 million (TRL4-6) to develop small electric commuter aircraft, the cost can be too high to bear for universities and start-ups, and the innovation paths may therefore take longer or stop altogether (IN6). The Green Flyway test arena has so far hosted a test for the Czech two-seater airplane ΦNIX, and Katla Aero and Heart Aerospace are set to test at a later stage. The project will however continue only until September 2022, after which testing may become difficult or cease altogether (IN2, IN8), due to the obligation to return any EU-funded infrastructure after the end of the project period (IN8).

4.3.2 F2 Knowledge Development

Overall the function *knowledge development* is rated as strong (3.8). The strength of the function mainly derives from Sweden being uniquely positioned in aerospace, electromobility, vehicles, automation, and battery technology (IN1, IN3, IN4, IN6). The TIS knowledge base is considered to be narrow, of high quality, albeit lacking in quantity. The knowledge base is considered sufficient to build the ES-19 (IN1, IN2, IN4), however more knowledge is needed for the innovation's market entry and diffusion phase, as well as to take the innovation to next phase of generational development (IN7). With regards to the next generation aircraft especially energy density of batteries need be improved (IN2, IN8), and to optimise aircraft design for electric aviation, knowledge on more aerodynamic and lighter structures may be needed (IN8). For the market entry and diffusion phase, there is also a lack of knowledge surrounding the supplying and managing of electricity and its infrastructure (IN3, IN8), new business models (IN9), co-financing (IN9) aircraft maintenance and handling (IN2) and standards for electric aviation (IN2). Recently, EASA has however started to include electric aviation in its roadmaps and discuss the certification process to a larger degree (IN7).

The actors involved in the knowledge development are considered competent, however only one interviewee believes there is a sufficient number of actors involved (IN3). From the side of industry, the interviewees would like to see the incumbent regime supply actors take part (IN2, IN4, IN7), as well as Siemens, ABB and Northvolt (IN2). Incumbent regime supply actors are thought to be able to deliver some of the many different sets of skills and knowledge needed for the development of the TIS, such as surrounding certification, production, sales and support (IN2). Other actors, such as Siemens, ABB and Northvolt could also contribute with knowledge surrounding batteries, power transmission, engines and automation (IN5, IN9). The underlying reasons for why these actors are not part could be due to electric aviation competing with existing products and trajectories (IN5, IN9), the absence of knowledge centres (IN4) and a clear agenda from the top level, and with that, incentives for gathering competent people. (IN3).

Vinnova is considered to be agile and to have a good understanding of risk (IN1), and RISE is considered competent in process management (IN11). Competence and knowledge surrounding electric aviation and the sector is however regarded as lacking among personnel at the funding agencies Vinnova and the Swedish Energy Agency, and the ability for them to act as sounding board in applying for different kind of funding (IN1). Finally, the new guidelines and regulations which will be needed for electric aviation may require a joint effort from government actors such as EASA, the Swedish Transport Agency, The Swedish Civil Aviation Administration, the Swedish Transport Administration, and The Swedish Civil Contingencies Agency (MSB) (IN8), the capacity of which may be inhibited due to budget constraints and a lack of appropriation directions to do so (IN5, IN12).

The knowledge base is funded indirectly via graduate and postgraduate aerospace education programmes and universities, as well as through Vinnova (IN1, IN4), the Nordic Council of Ministers (IN7), private capital (IN9) and the EU (IN4). There are no university programmes which specifically address electric aircraft (IN1, IN4, IN5), although students build drones at the programmes at Linköping University and thereby learn some basics in the underlying system of electric aircraft (IN1). A broad Master's programme within the transport area (Mobility), has been suggested to be launched in 2021, which would cover electrification as part of its aerospace track[9] (IN4, IN6). Similarly, the technology does not receive sufficient attention in national research and technology programmes. Although aeronautical research is primarily funded by the government through the National Aeronautical Research Program (IN6), it is steered by industry to a large degree, via Innovair (IN4). The funding is therefore mainly directed at incremental improvement of existing technologies. Likewise, the EU primarily supports incremental technology improvements, and the technology for electric aircraft is considered too mature to be eligible for basic research. The research system also requires calls for proposals which is linked to whether the technology receives attention and is seen as legitimate, which incumbent regime supply actors are seen as important for (IN4). Funding for the new technical-

[9] The Master's programme was approved to be launched after the data collection and processing period.

aspects of electric aviation, such as business model innovation, is considered especially difficult to receive (IN9).

4.3.3 F3 Knowledge Diffusion

Overall the function *knowledge diffusion* is rated as moderate (3.2). Electric aviation development is highly dependent on collaboration between a breadth of actors (IN9, IN8). While there are several learning networks available for electric aviation; Elise, NEA, and Green Flyway, sorted under the umbrella Fossil Free Aviation 2045, these are regarded as insufficient mainly due to a lack of financial resources (IN1, IN2, IN3, IN4, IN6, IN7, IN8). While Elise and NEA are funded through the Swedish government via Vinnova, and the Nordic Council of Ministers respectively, the participating actors finance the activities in kind (IN1). Due to the low level of financing, there are no actors able to dedicate themselves full-time to the projects (IN1, IN8). Several strong partnerships among regime actors are considered to exist, both in Sweden as well as in the EU, where in especially Clean Sky, large industrial actors merge together under research umbrellas and consortia to apply for research funding (IN5).

Green Flyway, NEA and Elise are considered to complement each other well (IN8), and the knowledge thought to be lacking surrounding commercialisation, business models and co-financing will be addressed in the Kvarken project, if it manages to secure funding (IN9). The networks are considered to be well-structured (IN7), transparent and open, consisting of mostly motivated actors (IN8, IN13), although some may have a more apprehensive approach and focus on positioning themselves rather than contribute, including one incumbent user (IN13, IN10). Interviewees agree that the networks include a wide representation of actors, although some would like to see more actors involved, as mentioned in section 4.3.2. Although the knowledge from the established actors are considered to be important to include by most interviewees, one actor fears that their inclusion would halt development, as they "do not speak the same language" and adhere to different business logics. By not being part of regime networks however, the TIS may miss out on the chance to develop knowledge and set agendas to guide the direction of search.

Moreover, there is a lack of collaboration between universities when it comes to knowledge that can be applied to electric aviation, such as aerodynamics, electrification and automation (IN4). Generally, cooperation among a wide range of actors can be difficult to manage, as working cultures and time horizons may differ considerably (IN8). Universities and research institutes are dependent on public financing, obligated to publish research findings, and are bound by rules on public procurement which is considered to slow activities and raise costs (IN1). The fact that a lot of the same actors are involved in the projects can make it a bit unclear what role one has in the respective projects, according to one interviewee (IN8).

4.3.4 F4 Guidance of the Search

The function *guidance of the search* is rated as moderate (3.4). The actors that are part of the TIS are driven by the possibility to reduce GHG emissions and bring greater accessibility to remote communities in Sweden (IN1, IN2, IN4, IN5, IN7, IN9). Other reasons have to do with the fact that the problem has not been solved yet (IN3), that it is new and exciting (IN5, IN8), and that it could be lucrative (IN5, IN6, IN8). The research institute RISE believes that electric aviation will strengthen competitiveness and contribute to sustainability in Sweden, which is one of their institute goals (IN7). The possibility of reducing noise (IN2) and bringing world peace (IN5) were also mentioned. Among the airports and airlines, it is ultimately about survival (IN7, IN9, IN13, IN10). SAS believes that it will become too expensive to emit GHG to carry on with existing technology (IN10), and the regional airports see the trend of increasingly larger aircraft concentrated to hubs as threats to their continued connectivity (IN11).

The reasons why actors may not want to become part of the TIS may be related to the long lead times in aircraft development and resulting long timeframe in achieving return on investment (IN6). An incumbent regime supply representative doubts whether the technology can deliver the promised range, and whether there is a market that is proportional to development costs (IN14). Others may believe that the technology will not work (IN7, IN8, IN9), the market will be too small (IN8) and will not bring sufficient economic gains (IN8). Similarly, some may fear that the innovation will not gather government support (IN8). Misconceptions concerning the environmental performance of electrical solutions such as surrounding battery manufacturing (IN7) as well as a prejudice that aviation is unsustainable by definition (IN4), may be other underlying reasons. A related reason may be the inability to re-write mental maps regarding aviation, as well as climate denial (IN2).

Among the TIS actors there is generally a belief in growth potential (IN12), and that it can become a global market replacing 40% of aviation (IN3, IN7). The incumbent regime supply actor representative is more sceptical about the growth potential of electric aviation, seeing that it may replace 10-15% of aviation at most, mainly due to a lack of belief in the speed of battery technology development and ability to achieve the required change in standards and regulations (IN14). This stance may be a barrier to other actor's belief in growth potential, as it influences the direction of the search set out in Innovair's Research and Innovation Agenda (NRIA) (IN4).

The technology has been represented in the media by the director of industry affairs at Swedish Aviation Industry Group, and received attention among politicians in different forums. There is however no long-term political goal, or support through specific policy programmes or policies in Sweden (IN8). In 2018, the Norwegian government set the goal of all short-haul flights in Norway being entirely electric by 2040, which is thought to have been important to the TIS guidance of the search (IN1, IN2, IN4, IN8). While there is a shared and clearly articulated goal for the system, the vision does not fit in the existing legislation. Standards have been built up around the existing technologies which differ considerably from those required for electric aviation (IN2, IN4). Examples include the need for a so-called single engine piston (SEP) qualification, which an electric aircraft does not have (IN2), as well as regulations surrounding fuel reserves which are more difficult for an electric aircraft to comply with (IN4). The lack of differentiation in takeoff and landing fees and the aviation tax, or alternatively that the revenues are recycled back into the state budget rather than into R&D, is seen as disincentivising airlines from investing in sustainable innovations (IN2, IN3, IN5, IN6, IN9), and adds to the idea that aviation is unsustainable per definition (IN4).

The airlines SAS and BRA have signed letters of intent and letters of interest, respectively (IN1, IN10). The airline BRA has signed a letter of interest, which means that they follow the developments with interest, but struggle to envision how these smaller constructions could replace any of their existing routes, and what new business models could look like (IN10). SAS has signed a letter of intent, which means that they could see these aircraft replace some of the procured air traffic routes in northern Sweden as well as some routes in Norway, but they, like BRA, struggle to envision the new business models which may be required (IN13). The state airport operator Swedavia is actively engaged in the TIS (IN8), and several regional airports have approached TIS actors to understand how they can prepare for the introduction of electric aviation (IN7). The Swedish Regional Airports (SRF), which represents these regional airports, is however more apprehensive, fearing that investments will be misguided, as there is a lack of standards for electric aviation and because biofuels has been the option on the political agenda in recent years (IN11).

4.3.5 F5 Market Formation

The function *market formation* is rated as moderate (2.6). There is no market for electric aviation today, but there is an aim to both replace the short distance regional routes as well as to create a new market (IN1). There is a clear trend of increasingly larger aircraft structures as the commercial aviation industry has long been driven by achieving a lower cost reduction per unit produced (IN13). Although the market for smaller aircraft is large, there has been a greater impetus to produce larger aircraft as achieving profitability for smaller aircraft is becoming increasingly difficult (IN13). As such, the smaller aircraft are no longer being produced, a segment the electric aircrafts could fill (IN13). The current aviation market for trips under 400 km in Sweden represents around five million passenger trips, which is believed to be able to be replaced by under 100 electric aircraft (IN1). The market for electric aviation could also be created through connecting previously unconnected regions, as well as taking shares from trips completed by car and railway, and by allowing for air commuting to work to become more common, leading to an increased demand for air travel (IN1). The certification level that Heart Aerospace is aiming for is the CS-23, which is mainly due to a lower certification burden (IN1). As briefly mentioned in section 4.3.4., these aircrafts are seen as eligible to replace routes that are covered by procured air traffic routes in northern Sweden as well as some routes in Norway, and the airlines would therefore prefer larger designs to fulfil existing business models of the remaining routes (IN13). Without a larger aircraft design, new business models would need to be created, and may require a new actor to achieve (IN8).

The EASA CS-23 certification level which Heart Aerospace is aiming for places certain design constraints which may be less than optimal (IN8). Rather than adapt the system to existing standards and institutions, these may instead need to be adapted to the system or be replaced by new ones (IN2, IN4). Safety concerns are paramount to aviation (IN14), but risk assessments do not currently include the effects of local air degradation or climate change (IN4). Further, requirements of reserve capacity significantly reduce the range for electric aircraft, and safety could instead be guaranteed through for example creating a regulatory framework to ensure that there are no air traffic stocks at the airports or conducting weather risk assessments before takeoff (IN1). The system of air traffic management is however considered to be conservative and slow, inhibited by lock-in to old technology driven by safety concerns which are not safety driving if taken from a basic principle analysis (IN4).

There is a need to change requirements surrounding the certification of parts and aircraft, airports and ground-based infrastructure, pilot training and certification, as well as air operations regulations and maintenance systems (IN1). Jet fuel infrastructure will for example need to be handled separately from electrical charging infrastructure, which will require substantial infrastructure changes (IN1). Energy supply and charging capabilities are seen as key by the airports, and as regulations and guidelines are not in place yet, the airports face uncertainties regarding how to plan for something that does not yet exist, and do not want to build tailored solutions to any individual actor (IN8, IN11). The institutional framework development therefore has to form an integral part of the technology development as to not delay the processes involved (IN1). This is an issue that NEA is working on, inspired by the moment when the Nordic countries created the global standard for telecommunication, whereby the government agency Televerket took an active role in the standardisation process (IN7). Similarly, The Swedish Transport Agency aims to support electric aviation by working proactively towards EASA to provide certification and are creating a network within the agency to monitor and manage the emergence of electric aviation (IN12). While there are no experts on electric aviation at the agency, the employees are considered competent to take on new forms of transport. A problem is that the budget is constrained, and these employees may be tasked with working on other projects, and mainly the focus has been on drones for urban mobility. Instead Norway has become a lead authority at EASA, and although the country has ambitious targets for the introduction of electric aviation, the Swedish Transport Agency have not yet noticed their presence at EASA. The regulations concerning aviation that are within the national jurisdiction are limited and concern mainly public protection and disaster relief (defence, police, fire brigade, etc.). While this could be a segment for electric aviation, there are currently no developments going on within this at the agency (IN12). Similarly, the Swedish Transport Agency is in charge of issuing the production license (POA), which is needed after receiving the design license from EASA to begin production of the aircraft, and one actor questions whether the Swedish Transport Agency has the competence and financial resources to become the world's first POA-country for electric aviation (IN5). Like the Swedish Transport Agency, EASA has in recent years seen cuts to their budget and may therefore not be able to employ the experts needed for a timely certification process (IN5). Finally, while regulatory activities are financed via taxes, the certification activities are paid through tariffs by the producer. As electric aviation has substantially different requirements from traditional technology, the financial burden for the pioneer may become insurmountable (IN5).

The uncertainties that potential buyers face concern whether the technology will work, be safe, and if it will bring sufficient economic benefits (IN1, IN6, IN7, IN9). A barrier to the purchase of electric aircraft is securing sufficiently long agreement periods, as it is difficult to expect there to be a salvage value (IN2), and generally, as the technology has yet to be established, the lifecycle costs are still unknown (IN4). These risks hinder the attainment of insurance which in turn makes it difficult to attract capital (IN4). Braathens Regional Airlines (BRA) sees the possibility of opening up new markets through new ways of thinking and new demands (IN10). There are however uncertainties regarding costs, as the profitability of smaller constructions is dependent on regulations such as e.g. minimum crew requirements (IN10). Scandinavian Airlines (SAS) is predominantly positive toward electric aviation, and especially intrigued by the possibility of achieving lower technical maintenance costs, a renewable energy supply, and using battery packs for energy storage in a smart grid (IN13). There are however uncertainties regarding what the educational and infrastructural demands will be, what permits will be needed, whether there are investors interested and surrounding state co-financing opportunities (IN13).

It is unclear what the public perception of electric aviation is, and uncertainties regarding current and future user needs. The Swedish "flygskam" trend or movement, roughly translated to flying shame, whereby one should feel ashamed of boarding a plane because of its negative environmental impact, could either contribute to the picture that all aviation is environmental harmful by definition or incentivise people to choose a more sustainable alternative if such exists (IN7, IN9). Analogous to the effects of cold temperatures on a mobile phone battery, there may be concerns surrounding the safety of flying an electric aircraft, and a period of building public perception may be required (IN13). In addition, without institutional balancing measures, the costs for the individual consumers may be considerably higher than for fossil fuel-based alternatives (IN9). The emergence of new routes could offer more flexible ways of travelling previously inconvenient routes and may increase the willingness to pay, as could the fact that electric aviation offers a more climate-friendly mode of transport (IN9). However, although aircraft designs have gotten smaller through the years, offering less space per passenger, one actor believes that the electric aircraft will not be able to provide the comfort that passengers expect (IN14), which may negatively affect their willingness to pay.

As electric aviation has yet to enter the market there are currently no institutional stimuli for market formation in Sweden (IN8). There are however negative stimuli in terms of a lack of a fuel tax, and lack of a differentiation of the aviation tax and in takeoff and landing fees (IN1, IN2). The possibility of introducing a differentiated takeoff and landing fee is however limited for the regional airports (IN11). The airlines trafficking regional airports often use old technology, and additional fees therefore pose the risk that their operations will cease entirely.

Likewise, due to their precarious financial state, the regional airports would not be able to compensate for any reduced fees for airlines using better technology (IN11).

4.3.6 F6 Resource Mobilisation

The function *resource mobilisation* is rated as moderate (2.6). While the technical competence is considered to be good, mainly due to enthusiasts having taught themselves (IN1, IN3, IN4), there is an insufficient number of people with this competence (IN1, IN9). Likewise, the individuals involved in the various projects surrounding electric aviation, such as NEA and Elise, are considered competent, although they are a small group (IN7). Competence at RISE, Vinnova, the Swedish Energy Agency, the Swedish Transport Agency, the Swedish Transport Administration, and the Swedish Civil Contingencies Agency, the The Swedish Civil Aviation Administration, and EASA may need to be strengthened (IN2, IN8). The reasons for why human resources have been lacking is mainly because electric aviation is new (IN5). It is also thought to be related to a lack of prioritisation and financial resources at government agencies, and a lack of legitimacy and government guidance of search stifling the formation of educational programmes (IN2, IN5). Hiring competent actors from other countries is also considered challenging as work permits and housing are difficult to obtain (IN1).

The financial resource base of the TIS has generally been weak. While the projects have mainly been funded by the government and in-kind by the participating actors, it is not considered sufficient for the further development of the innovation. Applying for funding through EU programmes involves a heavy administration burden which only very large actors can bear, and although the Swedish Transport Administration manages these applications, there are not enough human and financial resources within the TIS to pursue them (IN8). There is a lack of channels to attract venture capital in Sweden (IN1, IN4, IN8) which may be due to the country having few large foundations investing in early stages of development compared to other countries (IN8), although large pension funds could be an option (IN5). Venture capital is however considered to be more readily available internationally, and needs, like national venture capital, to be attracted (IN1, IN5), which is difficult due to the long lead times and high level of risk (IN1), and because the industry is considered to be mature and conservative and thus difficult to enter *(*IN4). Willingness to invest is considered to be a function of how much government funding and subsidy there is (IN1), as well whether the innovation is considered to be legitimate among incumbents and the government (IN5).

As mentioned, government funding is mainly channelled through Innovair, which explicitly does not fund start-ups and has to date not funded research in electric aviation, and the technology is not part of any other strategic innovation programme (IN1, IN8). The reason for a lack of funding into the TIS by Innovair is thought to be a result of the two incumbent regime supply actors steering the agenda and participating in assessing which research projects should be supported. According to a representative of one such actor, electric aviation is not pursued due to a lack of belief in the technology and market potential (IN14). As one of the two incumbent regime supply actors in Innovair manufactures turbine engine components, there exists little competence to judge whether there is potential in electric aviation, according to one interviewee (IN4), and because electric aviation competes with conventional technology for R&D funds, there is little incentive to support it, according to others (IN4, IN5). Another possibility is that an industrial consensus exists that it will be very difficult to build electric aircraft and make them a commercial success (IN6). It may also be related to difficulties in communicating and collaborating with each other, as the entrants and incumbents "do not speak the same language" and adhere to different business logics (IN9). Insufficient financial resources may also be due to the fact that the airline industry is one with tight margins and therefore is unable to drive development (IN4), and because the regional airports have seen declining revenues over a long period of time, and risk to, or have already, shut down (IN2). The inability of EASA, LFV and Swedish Transport Agency (IN2, IN5) to attract, develop or apply sufficient competence to facilitate certification and regulations in a timely manner is thought to be due to budget cuts in government and EU spending (IN2, IN5). Finally, the limit on state aid according to EU rules is well below the funding required for developing aircraft (IN1).

The physical resources are also generally considered to be weak. While there is a network of airports throughout Sweden (IN8), many of them risk to, or have already, shut down (IN5). The electricity grid is stable in most places in Sweden but will need to be expanded and strengthened as more parts of society are being electrified (IN8). Currently there is insufficient funding for the charging infrastructure that needs to be in place for the next phase of the innovation's development (IN1, IN2). Moreover, new traffic management systems will be needed, since electric aircraft are predicted to run at least partly autonomously, and the cost of these systems usually falls on the producer, which may be too high to bear (IN2). According to the Swedish Transport Agency everything is in place for legally testing engines and aircraft (IN12), and through Green Flyway there is a test arena for electric aviation (IN2). As mentioned in section 4.3.1 a problem is that Green Flyway will continue only until September 2022 (IN2), after which any physical infrastructure connected to the project must be returned to the EU (IN8). The cost of replacing the infrastructure would then fall on the financially constrained regional airports and/or municipalities, and testing activities therefore risks ceasing altogether, before Heart Aerospace manages to test their aircraft (IN8).

4.3.7 F7 Legitimacy Creation

The function *legitimacy creation* is rated as moderate (3.1). All interviewees agree that the legitimacy of electric aviation has improved significantly in recent years. Electric aviation was never spoken about only two years ago, and now it is frequently covered in the media (IN8, IN9), in a predominantly positive (IN3, IN7) and nuanced manner (IN7). Even though there is no political agenda for, or policy measures aimed at electric aviation, there has been a positive response to electric aviation from Swedish politicians (IN2, IN4, IN8), and representatives from all parliamentary parties attended the electric aviation event on February 11, 2020 (IN2, OB1). The event also received considerable press coverage (OB1).

The legitimacy creation is affected by the incumbent regime actors in divergent ways. Regime actors were part of the advisory board in the first stage of the Elise project (IN9), although one regime actor representative considers the statement of their involvement to be false due to an absence of official agreements (IN14). Further, Innovair, in their latest research and innovation agenda (NRIA), have highlighted electric propulsion as one, albeit small part, of the future mix of energy sources for aviation (IN8). It should be added however, that an incumbent regime supply actor representative, responsible for formulating that part of the agenda, thinks that the agenda will not be approved and that it only serves as a type of background document (IN14). One interviewee expressed having felt predominantly supported by incumbent regime supply actors (IN1) and according to another interviewee regime actors assisted in defining the initial electric aircraft concept (IN6). However, several of the interviewees expressed having experienced resistance coming from "old engineers" and some regime actors. The resistance has been expressed in social media, debating articles and in forums such as The Arlanda Airport Council which was appointed by the government to advise the national aviation strategy. The arguments against electric aviation most often concern the GHG reduction potential which is considered to be insignificant, especially compared to what can be achieved through fuel efficiency improvements, the introduction of biofuels and the hydrogen aircraft. Another argument is that electric aviation is too far in the future, perhaps viable in 20-30 years, and therefore not something that should receive funding today (IN2, IN4, IN8, IN9). Another way that the incumbent regime actors influence the TIS is by pursuing the innovation themselves, only half-heartedly, which results in slow development and failed experiments, and thereby stalling the innovation's overall development by deterring other actors from joining the TIS (IN4).

The underlying reason for regime resistance is among the interviewees thought to stem from calculations being based on horseless carriages, i.e. switching the energy source in traditional aircraft designs rather than the more system-changing designs envisioned in the TIS (IN3). For that reason, testing the technology and delivering proof that it works is considered important to be able to reduce resistance (IN2). However, the resistance may also have to do with the fact that electric aviation poses a threat to certain actors' value chain and competes for the same funding. The reason why TIS actors have not been able to convince the regime actors yet is thought to stem from the actors coming from different working cultures and using different languages, as the incumbents come from a long tradition of tight-knit actor-networks working toward a set vision with a learned way of thinking (IN1, IN3, IN9). The opinion of incumbent regime actors is important to the legitimacy of the TIS, as they decide over the direction of the search in aeronautical research via Innovair. In addition, these actors seem expect a certain level of political influence, as they reacted with surprise to not being formally included as an advisory function to the government assignment on electric aviation (OB2).

The TIS has benefitted from lobbying by Green Flyway, NEA and especially the Swedish Aviation Industry Group (IN1, IN2, N4). The latter is considered strong and competent (IN1), albeit comparably small on a global or European scale (IN5). The lobbying power of regime actors is thought to be stronger (IN4), and either the TIS could become a part of these or form their own, and preferably European-wide, lobbying organisation (IN5).

4.3.8 Functional Analysis Summary

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Figure 5 presents the overall assessment of the fulfilment of the seven key functions in the Swedish electric aviation innovation system. Entrepreneurial activities and knowledge development are the stronger points of system's functioning, even though there is room for improvement in both areas. The remaining five processes - knowledge diffusion, guidance of the search, market formation, resource mobilisation, and creation of legitimacy are all rated as moderate, with several areas in need of improvement.

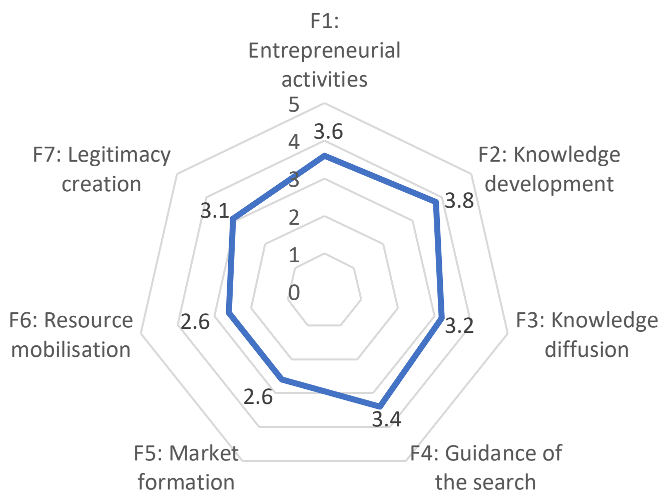

Figure 5. Overall assessment of the fulfilment of system functions

4.4 Identifying System Problems

With the structure of the Swedish electric aviation innovation system having been analysed, as well as its functioning assessed in relation to the technology stage of development, system problems can be identified. The analysis, which can be found elaborated in Appendix D: Structural-Functional Analysis shows that there are several mechanisms inhibiting the electric aviation innovation system, and there is a clear overlap between structural causes of identified problems.

Actor Problems

Actor problems can be characterised as presence-related when relevant actors are absent, and as capacity-related when actors lack competence, capacity to learn or utilise available resources, to identify and articulate their needs, and to develop visions and strategies (Wieczorek & Hekkert, 2012). Presence-related actor problems identified as hindering the innovation's functioning include a lack of a sufficient number of entrepreneurs and research institutes which affect the functions resource mobilisation and entrepreneurial activities. Gaps in the value chain is another presence-related actor problem seen as inhibiting both knowledge development and diffusion. The capacity-related actor problem characterising standardising and regulatory government agencies affect resource mobilisation, knowledge development, and market formation, through their inability to drive standardising and regulatory development. The absence of educational programmes is a capacity-related problem which is considered to limit knowledge development and resource mobilisation. Finally, actors' lack of capability in articulating demand is a capacity-related problem inhibiting both guidance of the search and market formation.

Institutional Problems

Institutional problems can be presence-related, which is when specific institutions are absent (Wieczorek & Hekkert, 2012). Institutional problems may also be capacity-related and classified as stringent, meaning problems may result in the so-called appropriability trap and favour incumbents, or they can be classified as weak, meaning that they insufficiently support new technologies or developments (Wieczorek & Hekkert, 2012). Presence-related institutional problems affecting the TIS include the absence of established practices and common habits among TIS participants affecting knowledge diffusion, as well as poorly understood and unaligned perceptions surrounding the technological, environmental and market performance affecting guidance of the search.

A weak capacity-related institutional problem was identified as pertaining to a general risk aversion in Sweden, which was seen as hindering entrepreneurial activities. Another was related to the absence of formal appropriation mechanisms causing apprehensiveness and a focus on positioning among some TIS network participants, affecting the quality of knowledge diffusion. The lack of political vision or agenda for electric aviation can be characterised as weak capacity-related institutional problem which affects legitimacy creation, guidance of the search, resource mobilisation, entrepreneurial activities, and knowledge development, if not all functions, as the drivers to contribute and participate in knowledge exchange is likely also affected. A related problem is the lack of prioritisation of electric aviation among government agencies, which is seen as affecting the capacity of government actors to mobilise human resources to develop knowledge required to drive standardisation and regulatory development, thus inhibiting the functions market formation, resource mobilisation and knowledge development. The presence of standards which have been developed to fit regime technologies rather than electric aviation can in turn be classified as a weak quality-related institutional problem, affecting market formation. A lack of channels to attract venture capital can also be characterised as a quality-related weak institutional problem which affects resource mobilisation and entrepreneurial activities. Finally, a lack of institutional incentives for market formation as well as lack of level playing field between regime and TIS technologies are seen as inhibiting market formation.

The obligations to follow rules on publishing and public procurement at universities and research institutes can be characterised as a stringent quality-related institutional problem which affects the speed and quality of knowledge diffusion. Similarly, the exclusion of start-ups from the strategic innovation programme for aeronautical research, Innovair, can be classified as a stringent capacity-related institutional problem which affects both resource mobilisation and entrepreneurial activities. The resource-intensive application process for EU funding as well as the obligation to remove EU-funded infrastructure after the end of the project period is a form of bureaucratic red tape which can be classified as a type of stringent quality-related institutional problem. This may block both entrepreneurial activities by threatening the longevity of testing infrastructure as well as the ability to mobilise further resources.

Interaction Problems

Interaction problems may be presence-related, which is when interactions are missing due to cognitive distance between actors, differing objectives, assumptions, capacities, or lack of trust (Wieczorek & Hekkert, 2012). Interaction problems may also be related to their quality, which may be weak, caused by a weak connectivity between actors, or strong, when some actors are wrongly guided by stronger actors and fail to supply each other with the required knowledge. The strong interaction problems may be caused by myopia, which is when there is an internal orientation favouring the incumbent set-up and relationships, blocking the necessity to open to external forces. Strong interaction problems may also be caused by an overly strong involvement of incumbent actors, a lack of (external to incumbents) weak ties which is valuable for breaking through an overly strong internal organisation, and finally strong interaction problems may be caused by a dependence on dominating partners due to assets specificity (Wieczorek & Hekkert, 2012).

The presence-related interaction problems hindering the TIS include a lack of collaboration among universities, affecting knowledge diffusion. Knowledge diffusion is also inhibited by cognitive distance and differing objectives among knowledge actors which limits quality of exchange in networks. Exclusion of TIS actors from the strategic innovation programme for aeronautical research Innovair, creates unequal participation in guidance of the search activities, and a globally weak advocacy coalition for electric aviation is considered to affect the creation of legitimacy. The TIS is further inhibited by quality-related interaction problems, one which can be classified as weak, in the case of the lack of complementary cooperative relationships, which negatively affects knowledge diffusion. The strong political influence of incumbent regime supply actors is a quality-related interaction problem which can be characterised as strong, inhibiting legitimacy creation. Similarly, the internal orientation of Innovair favours said actors and thereby hinders resource mobilisation, knowledge development and knowledge diffusion.

Infrastructural Problems

Lastly, infrastructural problems refer to physical, knowledge and financial infrastructure, and can be classified as presence-related, when a specific type of infrastructure is absent, or quality-related, when infrastructure is inadequate or malfunctioning (Wieczorek & Hekkert, 2012). A lack of financial infrastructure inhibits entrepreneurial activities, knowledge development, knowledge diffusion and market formation, as it is needed to fund R&D, as well as testing infrastructure and standardisation and regulatory development. Financial infrastructure is also needed to strengthen and expand the electricity grid in Sweden as well as to secure the future existence of regional airports and fund charging infrastructure at the airports. Additionally, government financial support is considered insufficient for the innovation's further development. These financial infrastructure problems tie in to the physical infrastructure needs which include the testing infrastructure, airports, electricity grid and charging infrastructure which if absent inhibit entrepreneurial activities and market formation.

4.5 Proposing Policy Instruments

The identification of system problems invariably leads to the question of how these problems can be addressed through policy intervention. The literature provides a toolbox of instruments which could address these problems (Kivimaa & Kern, 2016; Wieczorek & Hekkert, 2012). Interview participants have also suggested a number of different policy instruments which could be used in various configurations to address the identified problems, which can be found presented in list form in Appendix E: Interviewee Policy Instrument Suggestion and in Appendix D: Structural-Functional Analysis an attempt to link proposed policy instruments to functional problems can be found.

As mentioned in the previous section, there is a clear overlap between structural causes of identified problems. Moreover, functions are not independent, but rather reinforce one another, and as a result, these interdependencies magnify the impact of the mechanisms causing these problems. It could therefore be argued that policy should focus on reducing the strength of the mechanisms that have such a pervasive effect. The analysis has revealed several issues which may require extra policy attention: the lack of guidance of the search is a problem which can be considered as root, causing several other problems in the innovation system's function. Apart from that there are four issues that are particularly detrimental to the innovation system's functioning: a lack of funds for R&D, mainly attributed to Innovair and its governance structure; a need for investment in physical infrastructure and a lack of capacity of involved actors to invest; a need to create standards and a lack of capacity among government actors to work proactively in standard-setting; a poor articulation of demand, lack of incentives for market formation and a presence of market disincentives.

Policy Issue 1

A lack of guidance of the search by the government inhibits most, if not all functions. The governance structure of the strategic innovation programme, Innovair, is a result of government policy, and it in turn affects the government's guidance of the search through its de-/legitimising power – and they thus reinforce each other. The governance structure of Innovair is characterised by a dominance of two large incumbent regime actors. Due to factors such as the perceived threat to existing business models, cognitive distance and differing objectives, these actors predominantly resist the emerging TIS. This resistance is expressed in various framing activities in the public sphere, having an impact on the creation of legitimacy. Due to myopia - an internal orientation of Innovair favouring the incumbent set-up - the resistance also expresses itself in the exclusion of TIS actors from Innovair and a lack of funding in TIS technology R&D. A lack of funding in TIS knowledge development leads to slower technology development, inhibiting the ability to bring the innovation to its next stage of generational development. A lack of funding for entrepreneurial testing and demonstration inhibits the ability to convince and counteract resistance and with it the creation of legitimacy. The private willingness to invest in the TIS in turn is considered to be a function of the level of government funding and the legitimacy among incumbents and government, and financial resource mobilisation is thereby further hampered by their resistance, which in turn affects almost every other function. An exclusion of TIS actors from Innovair results in an unequal participation in guidance of the search activities. It also inhibits the diffusion of knowledge, such as surrounding standards and certification, which in turn inhibits market formation.

Addressing these underlying mechanisms via policy intervention could be achieved through setting a clear direction by creating a political agenda and goals for electric aviation, as suggested by several interview participants (IN2, IN3, IN4, IN4, IN5, IN8). Balancing the involvement of incumbent actors in Innovair could be achieved through a mandated inclusion of TIS actors, as suggested by Kivimaa and Kern (2016), and could lead to a more equal participation in the guidance of the search activities. As an underlying mechanism pertains to cognitive distance between actors, interaction between TIS and regime actors could be facilitated by the government, with measures such as: cooperative research programmes; consensus development conferences; cooperative grants and programmes; bridging instruments (centres of excellence, competence centres); collaboration and mobility schemes; policy evaluation procedures; debates facilitating decision-making; science shops; and technology transfer (Wieczorek & Hekkert, 2012). The government could also more actively reduce support for regime technologies, and direct funding toward electric aviation and other fossil free alternatives (Kivimaa & Kern, 2016). Finally, influence of incumbent regime actors could also be bypassed through the formation of new networks, as suggested by Kivimaa and Kern (2016), which could be in the form of a strategic innovation programme (IN1, IN3) or a national research programme for electric aviation (IN1, IN4, IN5). Integrating electric aviation related curricula into existing educational programmes or creating entirely new programmes could be another way of indirectly funding the knowledge development in the TIS (IN2, IN5).

Policy Issue 2

The lack of guidance of the search by the government is also expressed in the lack of prioritisation of electric aviation at the relevant Swedish government agencies. Not only is electric aviation not prioritised, but the agencies also lack capacity to develop the required knowledge to work proactively with standardisation and regulatory development, which is due to a lack of financial resources. Standards are a pre-requisite for bringing electric aviation to the market, and without it not only is market formation inhibited, but also the guidance of the search and the creation of legitimacy, through the influence of standards on perceptions surrounding the technology's market potential. The guidance of the search and creation of legitimacy in turn affect the remaining functions. These problems could be addressed by setting appropriation directions to work toward electrification of aviation, as well as aim to be lead authority or share the role with Norway at EASA (IN5), and through that set the required standards and regulations (Wieczorek & Hekkert, 2012). To increase the capacity among government agencies, the Swedish government could allocate sufficient funds in agency budgets (IN2, Wieczorek & Hekkert, 2012), deploy education and training programmes, as well as initiate policy labs (Wieczorek & Hekkert, 2012).

Policy Issue 3

A lack of physical infrastructure is another problem affecting the TIS. Entrepreneurial experimentation is dependent on testing infrastructure which is important to reduce uncertainties surrounding the technology and market potential, as well as to reduce resistance and increase the legitimacy of the innovation. To power an electric aircraft, an expansive and stable electricity grid is required and charging infrastructure at the airports needs to be in place. Aviation is also dependent on the existence of a market, and with the decline in the number of regional airports in Sweden, the market risks disappearing altogether. The absence of these physical resources not only affects market formation, but also the remaining functions, as a belief in market potential is an important underlying driver for the guidance of the search, creation of legitimacy and entrepreneurial experimentation, which in turn affect resource mobilisation, knowledge development, and knowledge diffusion.

The problem of a declining number of airports in sparsely populated areas in Sweden could be addressed through re-nationalisation, bringing them back under the Swedavia umbrella (IN2), but it could also be achieved through an increase in subsidies (Wieczorek & Hekkert, 2012). To address the need for investments into charging infrastructure, the Swedish government could provide subsidies (IN5), and establish or expand available grant schemes (IN2, IN13), or simply provide for it (Wieczorek & Hekkert, 2012). Finally, an expanded and strengthened electricity grid infrastructure is something the Swedish government could provide as well (IN8, Wieczorek & Hekkert, 2012).

Policy Issue 4

Lastly, the need to shift demand and the uncertainties regarding the market reaction creates a poor articulation of demand from users, which affects market formation as well as the guidance of the search, which in turn inhibits legitimacy creation and entrepreneurial experimentation. In addition, the absence of market incentives, the presence of market disincentives and lack of a level playing field further increases the difficulty for users in articulating their demand, and thereby blocks market formation. In effect, it reduces the guidance of the search and the legitimacy of the innovation, which has negative effects on all remaining functions.

The Swedish government could address the poor articulation of demand by becoming a user itself by nationalising domestic air traffic (IN14), and using innovation procurement (AD1, IN2, IN5, IN8). It could also extend the existing procurement of air traffic routes in northern Sweden to include new destinations, and set electrical propulsion as a requirement (AD1, IN2, IN4, IN5, IN8, IN13, IN14). The problem could also be addressed by supporting the articulation of demand through facilitating articulation discourse and brainstorming, and deploying awareness building measures (Wieczorek & Hekkert, 2012). To steer the market in the desired direction, a number of policy instruments which incentivise the purchase and use of the electric aircraft, as well as disincentivise the use of fossil fuel-driven aircraft could be deployed. Incentives could be in the form of purchase premiums, such as VAT and tax rebates (IN5, IN10), it could also be that the state makes a pre-emptive purchase of electric aircraft covering all or part of the capital cost by leasing out aircraft to future operators (AD1). Incentives could also be in the form of introducing new elements in tender contracts for procured routes, such as longer contracting periods and residual value guarantees (IN2). To increase fleet turnover and spur technological upgrades, the government could introduce an aircraft scrapping premium (IN14) and provide loan guarantees for purchasing (AD1, IN5, IN13).

Disincentivising legislation and policy measures could be abated or removed, such as through differentiating fees for air (NOx) and noise pollution (IN13), the aviation tax (IN1, IN5), and takeoff and landing fees, or exempting electric aviation entirely (IN1, IN5, IN9, IN13). Similarly, a lowered or removed energy tax for electric aviation could incentivise market formation through cost reduction (IN9, IN13). To disincentivise the purchase and use of fossil fuel aircraft and put pressure on the regime, the government could introduce a jet fuel tax (IN9, IN14) or raise existing fees and taxes, on for example carbon (IN14). It could also introduce a disclosure of environmental performance (eco-labelling system) (IN14), or apply a form of substitutions principle, that if it is possible to offer the same transport service in a more climate friendly way then that is required (IN14), and it can even go so far as to put an absolute requirement for using a particular traffic type (IN14), among public officials or otherwise.

5 Discussion

In this chapter, the findings are discussed against the reviewed literature, it also reflects on the results of the study. This study has found a number of problems which act as barriers to the development and diffusion of the Swedish electric aviation innovation system[10], as well as the structural causes of these problems[11]. The study has also found a number of policy instruments which could be deployed by the Swedish government to address these barriers[12], in order to facilitate the development and diffusion of electric aviation[13].

Although the level of specificity varied greatly among the policy instruments that were suggested by interviewees and in the literature, they represented the entire spectrum of instrument types in the Transport Analysis typology (PM 2018:2), and these could be implemented in various configurations to achieve policy goals. According to Kivimaa and Kern (2016), not only *creation* is important for niche innovations but also *destruction* or *destabilisation* of the incumbent socio-technical regime, as lock-in mechanisms and path dependence cause innovations within existing regimes to be mostly incremental and follow technical trajectories and therefore are difficult to change. By including the incumbent regime context structure in the TIS analysis, it became clear that the regime structures in fact did inhibit the electric aviation TIS functioning in several different ways. In line with Bergek et al (2015), the TIS-regime dynamics were however found to be more complex than expressing itself as mere resistance stemming from the regime, which is commonly emphasised in the TIS literature. Incumbent regime users, in this case one of the airlines, were found to participate in the development of the technology by defining their needs, acting as “lead users”, and thus influencing the guidance of the search. The activities of incumbent regime suppliers had divergent effects on the TIS, contributing both to legitimising and de-legitimising the TIS. Regime networks were found to mostly have a resisting effect on the TIS by blocking access to financial and knowledge resources. Sector-level institutions both had the effect of opening markets, via the possibility to certify an electric aircraft according to EASA CS-23, but also closed markets via strict safety regulations which in turn were seen by interviewees as resulting from dominant sectoral discourses, rather than holistic safety assessments. Similarly, electric aviation is dependent on the physical infrastructure that was created around the socio-technical regime, such as airports and runways, while requiring it to change to accommodate electric aviation. Taken together the regime structures were found to have a predominantly obstructive effect on the functioning of the electric aviation TIS, warranting policy attention.

The lock-in mechanisms that were found present in the case of biofuels, that airports and airlines are heavily invested in existing aircraft and infrastructure, with costs thus constituting a considerable barrier to their introduction (Kim, Lee & Ahn, 2019), were found in the electric aviation TIS as well. Market de-risking from the government via investments in niche use, followed by market incentives rewarding electric aviation which were suggested by Kim, Lee and Ahn’s (2019), were suggested by interviewees for the Swedish electric aviation TIS as well. In line with Kim, Lee and Ahn’s (2019), the interviewees also suggested directly subsidising the market price which could be achieved through funnelling emission surcharges from the use of fossil fuels. Kim, Lee and Ahn (2019) also suggested that the development of an open and public form of niche clusters, which was not suggested by the interview participants, but could be relevant to the electric aviation TIS as well. The authors argue that the intervention could lead to two key barriers being overcome. First it would reduce the burden on smaller firms that are

[10] RQ 1.1. *What are the barriers to the development and diffusion of electric aviation in Sweden?*

[11] RQ 1.2. *What are the underlying causes of these barriers?*

[12] RQ 1.3. *How can these barriers and their underlying causes be addressed through policy intervention?*

[13] Research objective: *How can the Swedish state contribute to the development and diffusion of electric aviation?*

unable to invest in R&D, allowing them to focus on the application of knowledge solely. Secondly, it would reduce the uncertainty surrounding the costs and benefits of different pathways, which would result in the elimination of inferior paths as well as increased investments into niche R&D and market infrastructure of more promising pathways (Kim, Lee & Ahn, 2019).

Kim, Lee and Ahn (2019) also suggested that the government should enable the articulation of social demand. According to the authors, the government should do so by nurturing science clusters that scientifically prove the impact of aviation on the environment, as well as diffuse this information to the public (Kim, Lee & Ahn, 2019). As there seems to be awareness of the environmental impact of aviation among the Swedish public, the government may need to find other routes to an articulated demand, such as procuring electric aviation, as suggested by several interview participants, or, as suggested by Wieczorek and Hekkert (2012), facilitating articulation discourse and brainstorming. Finally, Kim, Lee and Ahn (2019) suggested the implementation of a universal biofuel environmental certification. In the case of electric aviation, a more general eco-labelling scheme was suggested that would target all types of aircraft, as to increase awareness of the different environmental performances of aircraft, and nudge consumers to choose environmental superior alternatives, thus incentivising the phase-out of aging fleets – a measure likely to be ineffective in locations serviced by solely one airline, as in the case of several regional airports in Sweden.

The general themes that were found in the Swedish TIS analyses carried out by The Swedish Energy Agency (ER 2014:23), were found to also be affecting the electric aviation TIS, such as weak economic market incentives, and deficiencies in collaboration within the value chain and between authorities. Several of the same national system-external structures were also found to adversely affect the TIS, such as the lack of venture capital for major investments and the importance of the education system being able to meet the demand for new skills (ER 2014:23), indicating that the national innovation system in Sweden could be strengthened to benefit several eco-innovations.

Although a number of problems, structural causes and policy instruments to rectify them were identified in the analysis, several issues were found to warrant particular policy attention due to overlaps and interdependencies among functions and structural causes of problems. The lack of guidance of the search by the government can be seen as a systemic problem par excellence, as it obstructs most, if not all functions operating at the innovation system level, and can therefore be seen as a pre-requisite for addressing other policy issues. Policy issue 1 was more closely related to knowledge supply-problems surrounding the interface between *concept development* and *pilot and demonstration*, as conceptualised by Söderholm et al (2019) in Figure 3 and therefore require the deployment of mainly supply push instruments on the creative side, as well as systemic instruments on the destructive side addressing regime-level networks and support for regime technologies. Policy issues 2 and 3 were most closely related to the second interface, between *pilot and demonstration* and *market formation*, requiring the deployment of both technology push and systemic instruments. Policy issue 4 related to the third interface, between *market formation* and *diffusion* requiring mainly demand pull instruments, but also some supply push instruments through knowledge supply on the creative side. On the destructive side, demand-side instruments that put pressure on the regime by curtailing demand for regime technologies, as well as systemic instruments that would change regime rules were found likely to be required.

These results point to the need to apply a mix of instruments to achieve policy goals, in line with Howlett and Rayner's (2013) argument, and these instruments need to be combined in a coherent, congruent and consistent manner to achieve policy goals (Howlett & Rayner 2007; Kern & Howlett 2009), and such a portfolio design may require the re-assessment of seemingly unrelated policy goals and instruments. One such area that may be of particular relevance to electric aviation is regional development policy. In order for regional development policy to be in line with an electric aviation path, employment and other opportunities in sparsely populated and rural areas must be ensured as to leverage the increased accessibility.

The results also point to the need to address all phases of the technology's development (Söderholm et al, 2019). Although all phases of a technology's development need to be addressed, they do not necessarily have to be addressed at the same moment in time, as for example the deployment of eco-labelling schemes does little to support electric aviation during the concept development phase, pointing to the need to deploy instruments in a logical sequence. At the same time, certain structural elements may need to be in place at a later phase of the innovation's development that would require intervention today. The provision of electricity grid infrastructure is such an example – it may not be required by electric aviation in the near-term, but the deployment of that infrastructure may take several years, and if it is not in place at moment of market entry, it threatens to obstruct the innovation's diffusion entirely.

Timing is relevant not only to the policy instruments aimed at *creation* however, but also for *destruction,* as Kivimaa and Kern (2016) argue, "attention to the destruction side is particularly relevant when alternative innovations have already developed some momentum rather than being at a very early stage" (p. 207), as for example, a stifled domestic air travel demand in Sweden could put airports at increased risk of closure, and thereby threaten the future infrastructure for electric aviation. Apart from instrument timing (Steinhilber et al, 2011), other design criteria are important to consider as well. Flexibility*,* which is the extent to which actors are allowed to freely choose in which ways to comply with an instrument (Kivimaa & Mickwitz, 2006), varies considerably among the policy instruments suggested by interview participants. While the introduction of voluntary eco-labelling schemes offers a high degree of flexibility, an absolute requirement to use a particular traffic type offers none. A related criterion is stringency, which is the ambition level of an instrument (Kemp & Pontoglio, 2011). Fees, taxes and other surcharges need to be set at a rate high enough to disincentivise the use of fossil fuel aviation, without jeopardising the accessibility of remote communities and ability to invest in sustainable alternatives.

Finally, the level of government support needs to be taken into account as well (Steinhilber et al, 2011). EU competition laws place constraints on the level of state aid, amounts which the spurring of a new aviation paradigm is likely to exceed (IN1). There are several ways in which financial resources can be mobilised as to circumvent that barrier. By setting a clear political agenda and goals, private capital is likely to be attracted. Implementing such creative solutions as the Norwegian NOX-fund, whereby emission surcharges are funnelled to innovation investment via a private fund is another way to mobilise financial resources. Providing infrastructure, deploying educational programmes as well as strengthening the capacity of relevant government agencies to work proactively with standardisation and regulation, and with orchestrating social interaction and facilitating dialogue to leverage innovations, are other routes to indirectly fund the TIS. Another possible route to mobilise the financial resources required for electric aviation is through the setting of emissions reduction targets for the national defence and developing electric aircraft for military purposes. That way EU state aid rules do not apply. As was seen in Geels (2006) study, military R&D spending was imperative to the transition to turbojets and could be important in the next aviation transition as well. The major landscape changes currently unfolding, as a result of the global Covid-19 pandemic and increasing awareness of rapid climate change, could present a window of opportunity to introduce such a new interventionist policy paradigm. By incorporating a wider systems perspective, including the TISs technology-specific logic and its interrelated regime dynamics, as well as learning from such mission-oriented feats that led to putting humans on the moon (Mazzucato, 2016), the transition to turbojets (Geels, 2006), or creation of the global standard for telecommunication (IN7), the Swedish government could leverage electric aviation in order to contribute in the global effort to overcome the greatest challenge of our time - climate change.

5.1 Reflection on the Results

There are several limitations pertaining to the methodological choices of this study. The *boundary problem* is in principle a fundamental problem in any application of a systems approach, but especially pertinent in a social systems context, according to Olsson and Sjöstedt (2004). The critical issue is what perceivable elements should be considered to be a part of the system and what factors should be seen as belonging to its environment (Olsson & Sjöstedt, 2004). As this study aimed to capture both a TIS as well as its relationship to a regime context, which constitutes its own systems replete with its own set of complex interactions, the problem becomes yet more complicated. In line with a constructivist view, Olsson and Sjöstedt (2004) argue that the system boundaries can be established through the discretion of the researcher who makes use of their knowledge and earlier experience about similar problem situation in the process. The decision to draw the system boundaries in a specific way is however unavoidably influenced by the researcher's intuition, preferences and values. Furthermore, "the researcher will also have to consider the restrictions on the choice of boundaries imposed by the situation itself, the time and resources available to perform the study" (Olsson & Sjöstedt, 2004, p. 21). Due to the constraints placed on this study, the initial scoping was narrowed to two actors and one network pertaining to the regime context, and to one actor and the networks it is involved in for the TIS. During the interview process the boundary was continuously widened as participants highlighted other elements which they considered to be important. This had the effect that initial interviews included fewer and less specific follow-up and probing questions than the ensuing ones, and the scoping method may thus have led to important elements and their impacts being overlooked in the analysis. Furthermore, the spatial boundary places several constraints. Although it was loosely defined and considering some structural elements at the EU and international level, important interactions, especially surrounding the regime context, as well as entrepreneurial TIS developments, may have been omitted from the analysis.

The reviewed literature contained several non-peer-reviewed sources, and therefore the information gathered reflects the author's perception of reality, without considering the motivations behind their conceptions, and without having been externally verified. Likewise, the peer-reviewed sourced have been interpreted by the author and thereby filtered through their theoretical understanding of the subject matter. While the number and breath of actors interviewed should be sufficient to produce meaningful results, a broader representation of actor types was sought and especially more government actors would have been preferred. Moreover, the opinion of interview participants was used to inform the findings on identification of problems, as well as policy instruments to address them. As the majority of these participants are involved in the electric aviation TIS, they have a bias in the interventions they would like to see. Although the analysis tried to grasp the public's perception via the interviews, these were relayed via the interview participants through their constructions of reality, and thus the opinion of other stakeholders such as the general public were largely omitted from the analysis.

While the impacts of the Covid-19 pandemic are felt across all corners of society, not least in the aviation industry, it became clear that interview participants were acutely aware of the consequence on their responses. The interviewees would therefore answer from a perspective that the pandemic was not in fact ongoing and sometimes gave answers from the perspective of both scenarios. However, it is likely that participants answered questions differently than they would have as compared to prior to the outbreak.

The TIS framework provides the benefit of a systems perspective which enables a more holistic analysis than simply asking interviewees to relay perceived barriers. Questions are often reframed (as the different functions share several similarities) and participants are therefore urged to consider ideas in a different light, which was positively received and largely considered insightful. The comprehensiveness of the framework is both its greatest strength and a considerable weakness, as the interview guide was not only exhaustive but also exhausting. It could therefore have been more productive to pose fewer and more precise questions. The complexity of using the TIS framework should however not be understated. The framework strongly relies on the analyst having both a deep and broad knowledge base, and as it has not been elaborated, widely applied, or interpreted uniformly, it is difficult to build an understanding of how to use it from earlier applications. It has the consequence that the results are highly dependent on the interpretation and analysis of the researcher. Not only are participants constrained when answering questions from their knowledge base and constructed world, but so is the researcher, and as such it is possible that the wrong conclusions were drawn, 'objectively' speaking.

The research has successfully answered the research questions. However, it was beyond the scope of this study to design a specific policy instrument portfolio, considering design criteria, stakeholder involvement and wider effects of policy instrument implementation. Constructing such a portfolio requires complementing the study with ex-ante policy analyses. As the findings in this research are context-dependent they cannot be generalised without considering the context. The findings could however provide empirical evidence in favour or against established theory and findings, as was indicated in the previous section.

This work, to the best of the author's knowledge, is a first attempt at conducting a structural-functional TIS analysis while aiming to grasp its interrelated regime context. While several other context structures are likely to be important for the success of a TIS, the literature on socio-technical transitions indicates that lock-in of incumbent regimes are especially important. It is however likely that the inclusion of other context structures would have produced different results.

6 Conclusion

The final chapter concludes the research. It begins by summarising the research findings and discussion points and goes on to suggest a number of practical implications and recommendations for non-academic audiences. It concludes with a recommendation for future research.

Climate change is the greatest challenge of our time and needs to be addressed from all aspects of society. Global aviation's contribution to GHG emissions is large and growing, and the current pathways to sustainability are insufficient to be in line with the targets set out in the Paris Agreement. Electric aviation has emerged as an alternative that could form part of the solution, not only reducing emissions but also increasing accessibility and thus prosperity. Sweden has a long history in aviation as well as ambitious climate and transport policy objectives and therefore has the preconditions to contribute to the global efforts in mitigating climate change through proliferating the electric aircraft. In this light, this thesis set out to inform the Swedish government on policy instruments it could implement that contribute to the development and diffusion of electric aviation.

Research shows that lock-in of fossil-based systems constitute a considerable barrier to the transition to such sustainable innovations. Policy intervention needs thus not only be context- and technology-specific, but also incorporate a whole-systems view that accounts for the regime dynamics as well. For that reason, this thesis utilised a technological innovation systems (TIS) framework and lent concepts form the multi-level perspective (MLP) to account for the regime context structure, in order to identify problems to the development and diffusion of the electric aircraft and propose policy instruments to rectify them.

The thesis has shown that several problems hinder electric aviation, and these can be related to a number of structural causes. To spur electric aviation the government may need to implement a range of policy instruments as well as make adjustments to framework conditions. Creating market incentives, providing infrastructure, and increasing the capacity of government agencies to leverage innovations, are some important elements to such a policy intervention. Balancing incumbent actors' involvement in networks or the creation of new networks, as well as facilitating dialogue may be important as well. Most importantly the government must set the direction by setting a clear agenda and goals.

The design of policy instruments needs to consider several design criteria, such as their timing, flexibility, level of stringency and level of support, and these instruments need to be combined in a congruent, consistent and coherent manner, as to effectively achieve policy goals. There needs to be a simultaneous focus on creation of the new and destruction of the old in order to transition to a new aviation paradigm, and the current landscape changes resulting from the Covid-19 pandemic and increasing awareness of rapid climate change, may constitute a window of opportunity to do so.

6.1 Recommendations for Non-Academic Audiences

This research has identified problems which adversely affect electric aviation, as well as proposed policy instruments which could be implemented to address these. These findings may provide a starting point for further investigations into policy instruments for electric aviation. When designing policy instruments and policy mixes it is important to consider a range of design criteria as to achieve policy goals. When conducting similar investigations to these in the future, it may be wise to consider implementing a whole- or wider systems perspective in order to grasp more fully the factors which affect an innovation. Lastly, it should be noted that the TIS framework places emphasis on the identification of problems which should not be taken to imply that a TIS is not well-functioning. Rather it should be interpreted as a means by which to improve an innovation process.

6.2 Recommendations for Future Research

This study has attempted to incorporate the regime context structure in a TIS analysis. There are several other context structures which are important as well, and future research could focus on investigating more structures, or assessing the relative role of different context structures. Whole-system analyses could also investigate systems interaction with multiple TISs as well as multiple cross-sectoral regime dynamics. Further research could also investigate how to expand the TIS framework to better include the identification of different forms of lock-in. Furthermore, more research is needed on how to incorporate broader landscape type developments as well as transnational linkages.

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Appendix A: Consent Form

Consent to participation in research

Researcher: Kajsa Wimmerström
Supervisor at IIIEE: Sofie Sandin, Carl Dalhammar
Supervisor Transport Analysis: Fredrik Brandt

This study constitutes my degree project within the framework of the Master's Programme in Environmental Management and Policy at the International Institute for Industrial Environmental Economics (IIIEE) at Lund University. The aim of the study is to analyse policy measures that may be appropriate to implement in order to promote the development of and transition to a greater use of the electric aircraft. The request to participate in the study is sent to actors who are considered to be part of the innovation system of electric aviation. The study is based on a theoretical framework called Technological Innovation Systems (TIS) which means that the interview will follow a certain structure. You will be asked to assess the performance of a set of so-called "functions" on a 5-tier scales of absent-weak-moderate-strong-excellent, and answer in more detail to a set of in-depth questions. The aim of using this framework and interview protocol is to be able to capture the barriers to the development of electric aviation that individual actors themselves may not be aware of, by applying a systems perspective.

This study will be conducted through an interview with you that lasts about 90 min. Due to the Covid-19 pandemic, the interview will be held via Skype or Zoom, or over the phone. The interview will be recorded and transcribed. The data will be stored on my personal local hard drive and password-protected cloud service, and deleted at the end of the study. If you wish, the information that you provide can be handled anonymously in the study. This means that your name, your title, etc. will not be mentioned in the study. However, there is a risk that, due to small sample, some data will still be linked to individuals. Participation in the interview is voluntary and the respondent has the right, according to the Personal Data Act (1998:204), to cancel their participation and withdraw their consent both during and after the interview. Likewise, you are in no way obliged to answer all of the questions posed. There is a risk that you will share sensitive information and for this reason you may, if you wish, take part of the research findings and leave comments before publication.

I write the degree project on behalf of Transport Analysis but am not compensated financially or otherwise. The results of the interview study will be published in my Master's thesis and will in this form be published on Lund University's database Lund University Papers.

Due of the Covid-19, I do not want to request a physical written form of consent, instead I ask you to provide your consent by email. In the message, I wish you would copy one of the following two forms of consent:

- I agree to participate in the study on the transition to greater use of electric aircraft, and accept that my name, title, and my organization are included in the final product. I will get to approve the text before it is published.

- I agree to participate in the study on the transition to a greater use of electric aircraft but wish that the information I provide be handled anonymously in the final product.

Appendix B: Sample Interview Guide

1. Introductory Questions

- What does your business do?
- What is your role in the company?
- How are you involved in electric aviation?
- Which actors do you cooperate with on issues related to electric aviation?
- What phase would you say that the technology is in?
- What do you think the next phase looks like?

2. Diagnostic Questions

1. Entrepreneurial Activity

The first function is entrepreneurial activity: and this is the learning process by which uncertainty is reduced in the system, as entrepreneurs translate knowledge into business opportunities through market-oriented experiments

- Are there enough entrepreneurs experimenting?
- What kind of businesses are involved?
    - Established companies or new entrants?
- How many different experiments surrounding electric aircraft are being conducted?
    - Is there great variation between these experiments?
    - Are the activities of high quality?
- Is the experimentation of entrepreneurs an obstacle or driving force to enter the next phase in the development of the innovation?

➢ Overall, how would you assess the function entrepreneurial activity?
(0 = absent, 1 = very weak, 2 = weak, 3 = moderate, 4= strong, 5 = very strong)
    - What are the reasons for why the function entrepreneurial activity is not very strong?

2. Knowledge Development:

The second function is knowledge development which is the process by which the knowledge base is broadened and deepened, i.e. whether a sufficient knowledge base exists and if it can be used to realise the effort over a reasonable period of time and with reasonable resources.

- Is there access to critical knowledge for development and implementation?
- Are there technical problems that have not yet been overcome?
- How is the knowledge base in terms of quality and quantity?
- How wide or narrow is the knowledge base?
- Are there enough actors involved in the development of knowledge and are they competent?
- Who funds the knowledge development?
- maur
- Is knowledge sufficient to take innovation to the next phase?

➢ Overall, how would you assess the function knowledge development?
(0 = absent, 1 = very weak, 2= weak, 3= moderate, 4 =strong, 5 = very strong)
    - What are the reasons for why the function creation of legitimacy is not very strong?

3. Knowledge Diffusion:
The third function is knowledge diffusion which is the process by which knowledge is disseminated and combined in the system, i.e. whether there is a sufficient exchange of information.

- Are learning networks and R&D collaborations available?
  - Are these sufficient?
- Are there strong partnerships?
  - Between who?
- Is there any important type of actor that is missing in existing partnerships ?
- What is the dissemination of R&D, expertise and complementary knowledge along the different parts of the value chain?

➢ Overall, how would you assess the function knowledge diffusion?
(0 = absent, 1 = very weak, 2= weak, 3= moderate, 4 =strong, 5 = very strong)
  - What are the reasons for why the function knowledge diffusion is not very strong?

4. Guidance of the Search:
The fourth function is the guidance of the search which is the process that leads to a clear goal for the development of new technology based on actors' expectations, articulated user demand and societal discourse. This process enables selection, which guides the distribution of resources.

- What is it that makes actors want to get involved in this innovation?
  - Conversely, what is it that makes actors not want to get involved in this innovation?
- Is there belief in growth potential?
  - Conversely, what is it prevented by?
- Are there any customers who are experimenting with or are formulating a need for new solutions?
- Does the articulated vision fit in the existing legislation?

➢ Overall, how would you assess the function guidance of the search?
(0 = absent, 1 = very weak, 2= weak, 3= moderate, 4 =strong, 5 = very strong)
  - What are the reasons for why the function guidance of the search is not very strong?

5. Market Formation
The fifth function is market formation which is the process by which markets emerge and are shaped for the system's products, and involves the activities contributing to the creation of demand for new technology.

- What does the market look like?
- What is the size of the market (niche/developed)?
- Who are the potential users/buyers?
- What uncertainties do potential buyers face?
- Must a new market be created or an existing one be opened up?
- Are there institutional incentives or barriers for market formation?

➢ Overall, how would you assess the function market formation?
(0 = absent, 1 = very weak,2 = weak,3 = moderate, 4= strong, 5 = very strong)
  - What are the reasons for why the function market formation is not very strong?

6. Resource Mobilisation:
The sixth function is resource mobilisation which is the process by which actors in the system build up a resource base by pooling and building up financial, physical and human capital.

- Are there training programmes that provide the necessary skills?
  - Which ones?
- Is there sufficient availability of the right skills?
- Is there an adequate supply of risk capital?
- Is there sufficient public funding?
- Is there adequate physical infrastructure and other complementary resources?

➢ Overall, how would you assess resource mobilisation?
(0 = absent, 1 = very weak,2 = weak,3 = moderate, 4= strong, 5 = very strong)
  - What are the reasons for why the function resource mobilisation is not very strong?

7. Legitimacy Creation
The seventh function is legitimacy creation which is the process by which social acceptance is created for the system's technologies, actors and institutions among relevant stakeholders. This function thus brings together questions about the social, cultural and political acceptance and compatibility of technology with current regulations and laws.

- Is there alignment between the TIS and current legislation and standards?
- Is there resistance to change?
  - Where does it come from??
  - How does that this resistance manifest itself?
- Do actors, formal and informal institutions contribute sufficiently to the creation of legitimacy?
- How is technology depicted in newspapers and other media?
- Are any lobbying groups active in promoting the technology and/or influencing policymakers to the technology's advantage?
  - Are they large/strong?

➢ Overall, how would you assess the creation of legitimacy?
(0 = absent, 1 = very weak, 2 = weak, 3 = moderate, 4= strong, 5 = very strong)
  - What are the reasons for why the function creation of legitimacy is not very strong?

3. Closing Questions

- Are there any barriers to the development and diffusion of electric aviation that you would like to add?
- Are there any policy instruments that you think would be particularly important for electric aviation?
  - Are there policy instruments which you think would be relevant at different stages of the development of the innovation?
- Is there anything else that you would like to add?
- Is there any other person that you think I should interview?

Appendix C: Primary Data Sources

Interviews

ID	Position and organisation	Date
IN1	Founder & CEO of Heart Aerospace	20-03-2020 & 23-03-2020
IN2	Project lead for Green Flyway. Strategic advisor within infrastructure and president of a general aviation club	23-03-2020
IN3	Head of Research at QRTECH	25-03-2020
IN4	Researcher in electrical engineering at Uppsala University and academic coordinator for Elise	26-03-2020
IN5	Director Industry Affairs at Swedish Aviation Industry Group at the Swedish Confederation of Transport Enterprises	31-03-2020
IN6	Professor in Turbomachinery at Chalmers University of Technology. Board Member of Innovair	03-04-2020
IN7	Project Lead for Elise, NEA, Fossil Free Aviation 2045 and researcher in electromobility at RISE	03-04-2020
IN8	Senior Analyst at Swedavia	07-04-2020
IN9	Senior Project Lead for Elise, NEA, and cluster leader for Fossil Free Aviation 2045 at RISE.	08-04-2020
IN10	Sustainability Manager at BRA	30-03-2020
IN11	Project Lead at SRF	02-04-2020
IN12	Strategy and Regulatory Developer at the Swedish Transport Agency	02-04-2020
IN13	Head of Sustainability at SAS	09-04-2020
IN14	Specialist whole engine, holding various positions at GKN Aerospace Sweden. Adjunct Professor in propulsion engineering at Chalmers University of Technology. Cluster Leader in propulsion systems at Innovair/GKN Aerospace Sweden	28-04-2020

Supplemented interview data

ID	Type
AD1	Document provided by Heart Aerospace detailing suggestions for policy instruments

Observations

ID	Type	Date
OB1	Event concerning electric aviation at Bromma Airport, Stockholm	11-02-2020
OB2	Interview between the government agency Transport Analysis and representatives from engine-component manufacturer GKN Aerospace	03-04-2020

Appendix D: Structural-Functional Analysis

F1: Entrepreneurial activities

Parent problem	Child problem	Problem type	Instrument goal	Policy instruments suggested from the literature (Kivimaa & Kern, 2016; Wieczorek & Hekkert, 2012)	Policy instruments suggested by interview participants
Lack of entrepreneurs		Presence-related actor	Stimulate and organise participation of relevant actors	Clusters; new forms of Public Private Partnerships, interactive stakeholder involvement techniques; public debates; scientific workshops; thematic meetings; transition arenas; venture capital; risk capital	
	Risk aversion	Capacity-related weak institutional	Prevent too weak institutions	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	
	Lack of funding due to exclusion of startups from Innovair	Capacity-related stringent institutional	- Significant changes in regime rules - Prevent too weak and too stringent institutions	- Policies constituting, for example, structural reforms in legislation or significant new overarching laws. - Timely procurement (strategic, public, R&D-friendly); demonstration centres; strategic niche management; political tools (awards and honours for innovation novelties); loans/guarantees/tax incentives for innovative projects or new technological applications; prizes; Constructive Technology Assessment; technology promotion programmes; debates, discourses, venture capital; risk capital	
	Lack of channels to attract venture capital	Quality-related weak institutional	Prevent too weak institutions	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	Mandate more stringent and transparent environmental performance reporting, in the Annual Reports Act (1995:1554) (IN14)
	Lack of guidance of search by the government	Quality-related weak institutional	Prevent too weak institutions	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	Political agenda and framework (IN2, IN3, IN4) Clear political goals: e.g. market introduction in year 2025
Lack of long-term testing infrastructure		Presence-related physical infrastructure	Stimulate physical infrastructure	Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs	Strategic innovation programme for electric aviation (AD1, IN1, IN3)
	Lack of research institutes	Presence-related actor	Stimulate and organise participation of relevant actors	Clusters; new forms of Public Private Partnerships, interactive stakeholder involvement techniques; public debates; scientific workshops; thematic meetings; transition arenas; venture capital; risk capital	
	Obligation to remove EU-funded infrastructure after the end of the project period	Quality-related stringent institutional		Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	

F2: Knowledge development

Parent problem	Child problem	Problem type	Instrument goal	Policy instruments suggested from the literature (Kivimaa & Kern, 2016; Wieczorek & Hekkert, 2012)	Policy instruments suggested by interview participants
Lack of knowledge actors		Presence-related actor	Stimulate and organise participation of relevant actors	Clusters; new forms of Public Private Partnerships, interactive stakeholder involvement techniques; public debates; scientific workshops; thematic meetings; transition arenas; venture capital; risk capital	Technology competitions (IN1) Competence centres (IN1, IN4, IN5) National research programme for electric aviation (IN1, IN4, IN5) Strategic innovation programme for electric aviation (AD1, IN1, IN3) Creation of consortia (IN3, IN6) Education and training programmes (IN2, IN5)
	Insufficient dedicated R&D funds	Presence-related financial infrastructure	Stimulate financial infrastructure	Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs	Collect aviation tax revenues in a private fund, similar to Norway's NOX-fund, and spend on R&D (IN1, IN2, IN4, IN5, IN9, IN10) National research programme for electric aviation (IN1, IN4, IN5) Strategic innovation programme for electric aviation (AD1, IN1, IN3)
	Lack of educational programmes	Capacity-related actor	Create space for actors' capability development	Articulation discourse; backcasting; foresights; road-mapping; brainstorming; education and training programmes; technology platforms; scenario devel- opment workshops; policy labs; pilot projects	Education and training programmes (IN2, IN5)
Lack of capacity among some knowledge actors		Capacity-related actor	Create space for actors' capability development	Articulation discourse; backcasting; foresights; road-mapping; brainstorming; education and training programmes; technology platforms; scenario devel- opment workshops; policy labs; pilot projects	Competence centres (IN1, IN4, (IN5)
	Insufficient budget at government agencies	Presence-related financial infrastructure	Secure presence of hard institutions	Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs	Allocate funds to government agencies (IN2)
	Lack of prioritisation of electric aviation at government agencies	Quality-related weak institutional	Prevent too weak institutions	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	Appropriation directions to work toward electrification of aviation (IN5) Aim to be lead authority or share role with Norway at EASA (appropriation directions) (IN5)
Lack of guidance of search by the government		Quality-related weak institutional	Prevent too weak institutions	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	Political agenda and framework (IN2, IN3, IN4) Clear political goals (IN2, IN3, IN4, IN5, IN8)

F3: Knowledge diffusion

Parent problem	Child problem	Problem type	Instrument goal	Policy instruments suggested from the literature (Kivimaa & Kern, 2016; Wieczorek & Hekkert, 2012)	Policy instruments suggested by interview participants
Absence of specific actors		Presence-related actor	Stimulate and organise participation of actors	Clusters; new forms of Public Private Partnerships, interactive stakeholder involvement techniques; public debates; scientific workshops; thematic meetings; transition arenas; venture capital; risk capital	Strategic innovation programme for electric aviation (AD1, IN1, IN3) Creation of consortia (IN3, IN6)
Lack of complementary cooperative relationships		Quality-related weak interaction	Prevent too weak ties	Timely procurement (strategic, public, R&D-friendly); demonstration centres; strategic niche management; political tools (awards and honours for innovation novelties); loans/guarantees/tax incentives for innovative projects or new technological applications; prizes; Constructive Technology Assessment; technology promotion programmes; debates, discourses, venture capital; risk capital	Competence centres (IN1, IN4, (IN5)) Strategic innovation programme for electric aviation (AD1, IN1, IN3) Competence centres (IN1, IN4, (IN5)) Creation of consortia (IN3, IN6)
	Absence of established practices and common habits	Presence-related soft institutional	Secure presence of soft institutions	Awareness building measures; information and education campaigns; public debates; lobbying, voluntary labels; voluntary agreements	
	Lack of formal appropriation mechanisms cause apprehensiveness and focus on positioning among some participants	Capacity-related stringent hard institutional	Prevent too weak hard institutions	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	
	Some pariticpants bound by rules on publishing and public procurement	Capacity-related stringent hard institutional	Prevent too stringent hard institutions	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	
	Cognitive distance and differing objetives limit quality of exchange	Presence-related interaction	Stimulate occurance of interaction	Cooperative research programmes; consensus development conferences; cooperative grants and programmes; bridging instruments (centres of excellence, competence centres); collaboration and mobility schemes; polic evaluation procedures; debates facilitating decision-making; science shops; technology transfer	Strategic innovation programme for electric aviation (AD1, IN1, IN3) National research programme for electric aviation (IN1, IN4, IN5)
Lack of capacity for knowledge exchange due to lack of financial resources		Presence-related infrastructure	Stimulate financial infrastructure	Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs	Allocate funds for government agencies (IN2)
Lack of collaboration between universities		Presence-related interaction	Stimulate occurance of interaction	Cooperative research programmes; consensus development conferences; cooperative grants and programmes; bridging instruments (centres of excellence, competence centres); collaboration and mobility schemes; polic evaluation procedures; debates facilitating decision-making; science shops; technology transfer	Competence centres (IN1, IN4, (IN5)) National research programme for electric aviation (IN1, IN4, IN5)

F4: Guidance of the search

Parent problem	Child problem	Problem type	Instrument goal	Policy instruments suggested from the literature (Kivimaa & Kern, 2016; Wieczorek & Hekkert, 2012)	Policy instruments suggested by interview participants
Unaligned perceptions surrounding technological, environmental and market performance		Presence-related soft institutional	Secure presence of soft institutions	Awareness building measures; information and education campaigns; public debates; lobbying, voluntary labels; voluntary agreements	
	Lack of (long-term) testing infrastructure	Presence-related physical infrastructure	Stimulate physical infrastructure	Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs	Strategic innovation programme for electric aviation (AD1, IN1, IN3)
Lack of vision and goals from the government		Capacity-related weak hard institutional	Prevent too weak institutions	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	Political agenda and framework (IN2, IN3, IN4) Clear political goals (IN2, IN3, IN4, IN5, IN8)
Vision does not fit into existing legislation		Capacity-related weak hard institutional	Prevent too weak institutions	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	Aim to be lead authority or share role with Norway at EASA (regleringsbrev) Appropriation directions to work toward electrification of aviation (IN5) Allocate funds to government agencies (IN2)
Poor articulation of demand		Capacity-related actor	Create space for actors' capability development	Articulation discourse; backcasting; foresights; road-mapping; brainstorming; education and training programmes; technology platforms; scenario development workshops; policy labs; pilot projects	Extended procurement of air traffic and require electric aircraft (AD1, IN2, IN4, IN5, IN8, IN13, IN14)
Unequal participation in guidance of the search activities via Innovair		Presence-related interaction	Change social networks Stimulate occurance of interactions	K&K: Balancing involvement of incumbents for example in policy advisory councils with niche actors; formation of new organisations or networks to take on tasks linked to system change (Kivimaa & Kern, 2016) W&H: Cooperative research programmes; consensus development conferences; cooperative grants and programmes; bridging instruments (centres of excellence, competence centres); collaboration and mobility schemes; polic evaluation procedures; debates facilitating decision-making; science shops; technology transfer	

F5: Market formation					
Parent problem	**Child problem**	**Problem type**	**Instrument goal**	**Policy instruments suggested from the literature (Kivimaa & Kern, 2016; Wieczorek & Hekkert, 2012)**	**Policy instruments suggested by interview participants**
Lack of institutional incentives for market formation		Capacity-related weak hard institutional	Prevent too weak institutions	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	Differentiated takeoff and landing fees or exemption for electric aviation (IN1, IN5, IN9, IN13)
					Differentiated Aviation tax or exemption for electric avition (IN1, IN5)
					Differentiated environmental fees for air (NOx) and noise pollution (IN13)
					Lowered or removed energy tax for electric aviation (IN9, IN13)
					Pre-emptive purchase of electric aircraft covering all or part of the capital cost by leasing out aircraft to future operators (AD1)
					Extended procurement of air traffic and require electric aircraft (AD1, IN2, IN4, IN5, IN8, IN13, IN14)
					Applying a form substitutions principle, that if it is possible to offer the same transport service in a more climate friendly way then that is required (IN14)
					Absolute requirements for using a particular traffic type (IN14)
					Nationalization of air traffic (IN14)
					Innovation procurement (AD1, IN2, IN5, IN8)
					Purchase premiums - tax rebate, VAT rebate (IN5, IN10)
					Aircraft scrapping premium (IN14)
					New elements in tender contracts (for procured routes) such as residual value guarantees and longer contracts (IN2)
					Loan guarantees (AD1, IN5, IN13)
					Expand the Climate Leap initiative to include a couple of small electric aircraft per year, as the development of smaller have effect on larger (IN5)

F5: Market formation (Continued)					
Parent problem	**Child problem**	**Problem type**	**Instrument goal**	**Policy instruments suggested from the literature (Kivimaa & Kern, 2016; Wieczorek & Hekkert, 2012)**	**Policy instruments suggested by interview participants**
Lack of level playing field between technologies		Capacity-related weak hard institutional	- Put pressure on regimes - Prevent too weak institutions	- Control policies - such as taxes, import restrictions, and regulations. Control policies, for example, may include using carbon trading, pollution taxes, road pricing or bans to put economic pressure on current regimes - Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	Jet fuel tax (IN9, IN14) Disclosure of environmental performance (eco-labelling system) (IN14) Introduce a carbon tax (IN14) Applying a form substitutions principle, that if it is possible to offer the same transport service in a more climate friendly way then that is required (IN14) Absolute requirements for using a particular traffic type (IN14) Mandate lower cruising altitude of aircraft (IN6)
Poor articulation of demand		Capacity-related actor	Create space for actors' capability development	Articulation discourse; backcasting; foresights; road-mapping; brainstorming; education and training programmes; technology platforms; scenario development workshops; policy labs; pilot projects	
Absence of standards		Capacity-related weak hard institutional	Prevent too weak institutions	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	Appropriation directions to work toward electrification of aviation (IN5) Aim to be lead authority or share role with Norway at EASA (appripation directions) (IN5)
	Lack of capacity among government agencies	Capacity-related actor	Create space for actors' capability development	Articulation discourse; backcasting; foresights; road-mapping; brainstorming; education and training programmes; technology platforms; scenario development workshops; policy labs; pilot projects	Allocate funds to government agencies (IN2)
	High cost of standard procedures	Presence-related financial infrastructure	Stimulate financial infrastructure	Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs	
Insufficient electricity grid and lack of charging infrastructure		Presence-related physical infrastructure	Stimulate physical infrastructure	Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs	Establish or expand available grant schemes to develop charging infrastructure (IN2, IN13) Subsidies for electrification of airports (IN5) Expand and strengthen electricity grid infrastructure (IN8)
Decreasing number of regional airports		Presence-related financial infrastructure	Stimulate financial infrastructure	Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs	Re-nationalisation of regional airports (IN2)
Lack of guidance of search by government		Capacity-related weak hard institutional	Prevent too weak institutions	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	Political agenda and framework (IN2, IN3, IN4) Clear political goals (IN2, IN3, IN4, IN5, IN8)

F6: Resource mobilisation					
Parent problem	**Child problem**	**Problem type**	**Instrument goal**	**Policy instruments suggested from the literature (Kivimaa & Kern, 2016; Wieczorek & Hekkert, 2012)**	**Policy instruments suggested by interview participants**
Lack of guidance of search by government		Capacity-related weak hard institutional	Prevent too weak institutions	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	Clear political goals (IN2, IN3, IN4, IN5, IN8)
Human					
Lack of human resources		Presence-related actor	Stimulate and organise participation of actors	Clusters; new forms of Public Private Partnerships, interactive stakeholder involvement techniques; public debates; scientific workshops; thematic meetings; transition arenas; venture capital; risk capital	Education and training programmes (IN2, IN5)
	Lack of educational programmes	Capacity-related actor	Create space for actors' capability development	Articulation discourse; backcasting; foresights; road-mapping; brainstorming; education and training programmes; technology platforms; scenario devel- opment workshops; policy labs; pilot projects	National research programme (IN1, IN4, (IN5))
	Lack of capacity among government agencies	Capacity-related actor	Create space for actors' capability development	Articulation discourse; backcasting; foresights; road-mapping; brainstorming; education and training programmes; technology platforms; scenario development workshops; policy labs; pilot projects	
	International recruitment difficult due to work permits and housing are hard to obtain	Capacity-related stringent institutional	- Significant changes in regime rules - Prevent too stringent institutions	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	
Physical					
Insufficient electricity grid and lack of charging infrastructure		Presence-related physical infrastructure	Stimulate physical infrastructure	Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs	Establish or expand available grant schemes to develop charging infrastructure (IN2, IN13) Subsidies for electrification of airports (IN5) Expand and strengthen electricity grid infrastructure (IN8)
Decreasing number of regional airports		Presence-related financial infrastructure	Stimulate financial infrastructure	Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs	Re-nationalisation of regional airports (IN2)
Lack of long-term testing infrastructure		Presence-related physical infrastructure	Stimulate physical infrastructure	Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs	Strategic innovation programme for electric aviation (AD1, IN1, IN3)
Lack of research institutes		Presence-related actor	Stimulate and organise the participation of relevant actors	Clusters; new forms of Public Private Partnerships, interactive stakeholder in- volvement techniques; public debates; scientific workshops; thematic meetings; transition arenas; venture capital; risk capital	

F6: Resource mobilisation (Continued)					
Parent problem	**Child problem**	**Problem type**	**Instrument goal**	**Policy instruments suggested from the literature (Kivimaa & Kern, 2016; Wieczorek & Hekkert, 2012)**	**Policy instruments suggested by interview participants**
Financial					
Insufficient government funding		Presence-related financial infrastructure	- Reduced support for regime technologies - Stimulate financial infrastructure	- Withdrawing support for selected technologies (e.g.cutting R&D funding, removing subsidies for fossil fuel production or removing tax deductions for private motor transport) - Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs	
	Incumbent regime network excludes startups	Capacity-related stringent institutional	- Significant changes in regime rules - Prevent too stringent institutions	- Policies constituting, for example, structural reforms in legislation or significant new overarching laws. - Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	
	Internal orientation at Innovair leads to funding of regime technologies	Capacity-related strong interaction (Myopia)	- Prevent too strong .and too weak ties - Changes in social networks, replacement of key actors	- Balancing involvement of incumbents for example in policy advisory councils with niche actors; formation of new organisations or networks to take on tasks linked to system change - Timely procurement (strategic, public, R&D-friendly); demonstration centres; strategic niche management; political tools (awards and honours for innov- ation novelties); loans/guarantees/tax incentives for innovative projects or new technological applications; prizes; Constructive Technology Assessment; technology promotion programmes; debates, discourses, venture capital; risk capital (W&H)	
	Resource-intensive application procedures for EU funding	Capacity-related stringent hard institutional	Prevent too stringent institutions	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	
Insuffient private funding		Presence-related financial infrastructure	- Reduced support for regime technologies - Stimulate financial infrastructure	- Withdrawing support for selected technologies (e.g.cutting R&D funding, removing subsidies for fossil fuel production or removing tax deductions for private motor transport) - Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs	Collect aviation tax revenues in a private fund, similar to Norway's NOX-fund, and spend on R&D (IN1, IN2, IN4, IN5, IN9, IN10)
	Lack of channels to attract venture capital	Quality-related weak institutional	Prevent too weak institutions	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	Mandate more stringent and transparent environmental performance reporting, in the Annual Reports Act (1995:1554) (IN14)

F7: Legitimacy creation					
Parent problem	**Child problem**	**Problem type**	**Instrument goal**	**Policy instruments suggested from the literature (Kivimaa & Kern, 2016; Wieczorek & Hekkert, 2012)**	**Policy instruments suggested by interview participants**
Lack of guidance of search by government		Capacity-related weak hard institutional	Prevent too weak institutions	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms	Political agenda and framework (IN2, IN3, IN4) Clear political goals (IN2, IN3, IN4, IN5, IN8)
Lack of long-term testing infrastructure		Presence-related physical infrastructure	Stimulate physical infrastructure	Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs	Strategic innovation programme for electric aviation (AD1, IN1, IN3)
Cognitive distance and differing objectives limit quality of exchange		Presence-related interaction	Stimulate occurance of interaction	Cooperative research programmes; consensus development conferences; cooperative grants and programmes; bridging instruments (centres of excellence, competence centres); collaboration and mobility schemes; policy evaluation procedures; debates facilitating decision-making; science shops; technology transfer	
Strong political influence of incumbent regime actors		Quality-related strong interaction	- Prevent too strong ties - Changes in social networks, replacement of key actors	- Balancing involvement of incumbents for example in policy advisory councils with niche actors; formation of new organisations or networks to take on tasks linked to system change - Timely procurement (strategic, public, R&D-friendly); demonstration centres; strategic niche management; political tools (awards and honours for innovation novelties); loans/guarantees/tax incentives for innovative projects or new technological applications; prizes; Constructive Technology Assessment; technology promotion programmes; debates, discourses, venture capital; risk capital	
Weak advocacy coalition		Presence-related interaction	- Changes in social networks, replacement of key actors - Stimulate occurrence of interactions	- Balancing involvement of incumbents for example in policy advisory councils with niche actors; formation of new organisations or networks to take on tasks linked to system change - Cooperative research programmes; consensus development conferences; cooperative grants and programmes; bridging instruments (centres of excellence, competence centres); collaboration and mobility schemes; polic evaluation procedures; debates facilitating decision-making; science shops; technology transfer	

Appendix E: Interviewee Policy Instrument Suggestion

Policy Instrument	Proposed by
Differentiated takeoff and landing fees or exemption for electric aviation	IN1, IN5, IN9, IN13
Differentiated Aviation tax or exemption for electric avition	IN1, IN5
Removal of Swedavia's required rate of return on equity	IN10
Differentiated environmental fees for air (NOx) and noise pollution	IN13
Extend procurement of air traffic and require electric aircraft	AD1, IN2, IN4, IN5, IN8, IN13, IN14
Pre-emptive purchase of electric aircraft covering all or part of the capital cost by leasing out aircraft to future operators	AD1
Loan guarantees	AD1, IN5, IN13
Creation of consortia (IN3, IN6) - granting advantageous conditional loans, which require that established companies risk large amounts (IN6)	IN3, IN6
Lowered or removed energy tax for electric aviation	IN9, IN13
Jet fuel tax	IN9, IN14
Carbon tax	IN14
Absolute requirements for using a particular traffic type	IN14
Applying a substitutions principle, that if it is possible to offer the same transport service in a more climate friendly way then that is required	IN14
Nationalisation of air traffic	IN14
Aircraft scrapping premium	IN14
Disclosure of environmental performance (eco-labelling system)	IN14
Premium for buying electric aircraft - tax rebate, VAT rebate	IN5, IN10
Innovation procurement	AD1, IN2, IN5, IN8
Substitute mandated climate compensation of government travel with substitution principle	IN14
Expand the Climate Leap initiative to include a couple of small electric aircraft per year, as the development of smaller have effect on larger	IN5
Aviation tax revenues to NOX-fond	IN1, IN2, IN4, IN5, IN9, IN10
Mandate more stringent and transparent environmental performance reporting, in the Annual Reports Act (1995:1554)	IN14
Aim to be lead authority or share role with Norway at EASA	IN5
Appropriation directions to work toward electrification of aviation	IN5
Allocate funds for government agencies	IN2
Establish or expand available grant schemes to develop charging infrastructure	IN2, IN13
Re-nationalisation of regional airports	IN2
Subsidies for electrification of airports	IN5
Competence centres	IN4, IN5
Technology competitions	IN1
Strategic innovation programme for electric aviation	AD1, IN1, IN3
National research programme for electric aviation or similar to secure research funding	IN1, IN4, IN5
Education and training programmes	IN2, IN5
Political agenda and framework	IN2, IN3, IN4
Clear political goals (IN2, IN3, IN5), (e.g. market introduction in year 2025 (IN4, IN8)	IN2, IN3, IN4, IN5, IN8
New elements in tender contracts (for procured routes) such as residual value guarantees and longer contracts	IN2
Mandate lower cruising altitude of aircraft	IN6