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Pursuing Aviation Biofuels

A Diagnostic Analysis of the Swedish Biojet Innovation System

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Reaching the conclusion of this Master Thesis, I am well aware that this work has not been the result of solely my individual effort. I am thereby dedicating these lines to sincerely thank all those who have helped me achieving this goal.

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Abstract

Globally, aviation biofuel (*biojet*) technology has reached a degree of progress that allows immediate substitution of conventional fossil fuel in commercial air travel. However, numerous factors constitute an impediment to its large-scale use and deployment: a diagnostic analysis identifying key obstacles to biojet development is needed. For this reason, an examination of actors, institutions and activities existing in the Swedish landscape is performed. The research uses the System of Innovation framework to identify key factors having an impact on the biojet innovation process and to map out the current state of play.

The analysis indicates that a large number of actors and institutions can influence the innovation system. Only a limited amount of organisations is proactively contributing to the system success, whereas a large group of actors are generally favourable to biojet development but participate somewhat passively to the innovation process. In particular, a major barrier to development is constituted by the scarce involvement of the Swedish public authority, which could foster the innovation process by setting binding targets, providing financial incentives and encouraging collaboration among stakeholders. Limits in the significance of results are due the categorisation approach, which prevents to consider the whole picture of the innovation system, and due to the inability of comparing the Swedish system with other national studies; the latter issue can be overcome by conducting analogue research in other settings.

Keywords: Aviation biofuel, Biojet, System of Innovation, Diagnostic analysis.

Executive Summary

In recent times, the international commercial aviation sector has been pressured to curb its impact on the environment. Use of aviation biofuel (*biojet*) has been identified as the most suitable solution to tackle this issue, due to better environmental performance than conventional fuel and facility of replacement within existing infrastructure. However, biojet is an innovative product currently undergoing its infancy phase of development, and numerous obstacles hamper the pace of increasing production and use. For understanding the complex dynamics that affect biojet development it is necessary to consider the overall process of innovation creation, development and diffusion, highlighting the role of different players and the activities they perform. The objective of this study is therefore to identify the actors and institutions involved in the Swedish biojet innovation system, the required steps to establish a regional biojet supply chain and the most effective actions to promote biojet use. The research provides an assessment of the existing state of play, identifying key determinants for biojet production, implementation and diffusion.

The study follows a qualitative approach to map out the system constituents and describe their features and activities. In addition to peer-reviewed articles and grey literature, data has been retrieved through the conduction of 18 interviews with key stakeholders. The System of Innovation (SI) framework has been chosen for conducting the research. The framework characteristics, mainly based on the work of Edquist (2005), have been customised for the analysis of the biojet innovation system. In so doing, seven key activity groups have been defined and analysed.

The analysis provides information on system organisations, institutions and activities. In particular:

- Research and development activities denote a triangular collaboration between privates, public bodies and the academia. Although many research activities are carried out and encouraged, the degree to which they target specifically the area of aviation biofuel is somewhat limited.
- Aviation self-imposed targets and institutional documents calling for sustainable fuel transition contribute to the creation of a market demand only to certain extent, whereas a lack of binding targets and market-based instruments is observed. However, promising signals, such as the announcement of the ICAO market-based measure for international aviation to be operative from 2020, can be detected. The scarce government interest in aviation sustainability is recognised as a major hurdle and is addressed through lobbying activities performed by various stakeholders, though with limited results.
- Internationally accepted ASTM standards allow the blending of up to 50% of biojet with conventional fuel and recognise various processes for the production of alternative fuel. Alternative processes are currently undergoing certification. On the other hand, a lack of clarity with regard to biojet sustainability criteria is observed; an intense dialogue between stakeholders to provide more accurate definitions is taking place.
- A large number of organisations can influence the innovation process. These organisations include supply chain actors (producers, distributors and users), public authorities, research bodies, and interest groups. A small group of forerunners are leading the innovation process; their activities are vital for its success. Contrariwise, many organisations are generally favourable to biojet development but participate passively to the innovation process. Among these lay potential key actors.

- Dialogue among organisations is facilitated by strong connections within and outside the supply chain. Multi-stakeholder collaborations are a driver to innovation, leading to the most promising projects thanks to the synergies they can achieve.
- Laws at the national, European and international level govern biojet technology and diffusion. The current legislative framework provides unclear regulation over some biojet-related issues such as definition of sustainability, and gives limited support to biojet development. A number of embedded rules, norms and behaviours have been recognised to affect the innovation process more positively than negatively.
- Financing support provided by private and public actors can facilitate raising initial capital for biojet-related research project and SMEs. The most problematic financial barrier for biojet deployment appears to be market competitiveness. The price gap between conventional fuel and biojet is not being addressed by legislation, as no financial incentives are currently in place. Various financing mechanisms are being proposed but no agreement among stakeholders has been reached.

While this analysis can describe to a large extent the innovation system status, drivers and barriers, it is noted that the categorisation system provides fragmented results, and it is therefore problematic to have a full picture of the system and to identify which components are most crucial for success. Additionally, it is noted that the study fails to pinpoint important linkages between activity groups that have a strong influence on the innovation system. Furthermore, it is observed that the study is limited in its significance by the fact that no equivalent national studies can be used for comparison. The inability to compare the innovation system with parallel systems with different features additionally hampers the identification of key components for success. Future research should fill these data gaps by performing similar innovation system studies in other countries.

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Abbreviations

ACA	Airport Carbon Accreditation
ACARE	Advisory Council for Aeronautics Research in Europe
AFTF	Alternative Fuel Task Force
AIREG	Aviation Initiative for Renewable Energy in Germany
Alfa-Bird	Alternative Fuels and Biofuels for Aircraft Development
ATAG	Air Transport Action Group
ATJ	Alcohol To Jet
BC	Black Carbon
CAAFI	Commercial Aviation Alternative Fuels Initiative
CAEP	Committee on Aviation Environmental Protection
CDM	Clean Development Mechanism
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DME	Dimethyl Ether
DSHC	Direct Sugar to Hydro Carbons
EC	European Commission

EBTP	European Biofuels Technology Platform
EEA	European Economic Area
EFTA	European Free Trade Association
ETC	Energy Technology Centre
EU	European Union
EU-ETS	European Union Emission Trading Scheme
F-T	Fischer-Tropsch
FGF	Fly Green Fund
GBER	General Block Exemption Regulation
GDP	Gross Domestic Product
GFAAF	Global Framework for Aviation Alternative Fuels
GHG	Greenhouse Gas
HDCJ	Hydrotreated Depolymerised Cellulosic Jet
HEFA	Hydroprocessed Esters and Fatty Acids
HVO	Hydrogenated Vegetable and Animal Oils and Fats
IATA	Internation Air Transport Association
ICAO	International Civil Aviation Organisation
ILUC	Indirect Land Use Change
IPCC	International Panel on Climate Change
ITAKA	Initiative Towards Sustainable Kerosene for Aviation
MSW	Municipal Solid Waste
NEFI	Network of European Financial Institutions for Small and Medium Sized Enterprises
NGO	Non-Governmental Organisation
NISA	Nordic Initiative for Sustainable Aviation
NO_X	Nitrogen Dioxides
OC	Organic Carbon
OECD	Organisation for Economic Co-operation and Development
R&D	Research and Development
SAAFA	Sustainable Alternative Aviation Fuels Activity
SAS	Scandinavian Airlines
SEK	Swedish Krona
SFC	Swedish Gasification Centre
SI	System of Innovation
SIP	Synthesised Iso-Paraffinic
SMEs	Small and Medium Enterprises
SO_2	Sulphur Dioxide
STEM	Swedish Energy Agency
SWAFEA	Sustainable Way for Alternative Fuels and Energy for Aviation
TS	Swedish Transport Agency

UN	United Nations
US	United States
VAT	Value-Added Tax
VOC	Volatile Organic Compound
WTO	World Trade Organisation
°C	Degree Celsius

1 Introduction

1.1 Background and significance

1.1.1 Climate change: causes and consequences

Even though environmental economics literature started to develop in the 1950s and 1960s with a series of seminal publications concerning natural resource scarcity and limits to economic growth, climate change has not been a mainstreamed area up until the recent years (D. Pearce, 2002). For a long period, growing public awareness received limited attention from national authorities, regardless of the warnings from the scientific community. Then, in a very short time span in the beginning of the 21st century, interest towards environmental issues suddenly rocketed at the national and international level across the world (Giddens, 2008).

The latest report by the Intergovernmental Panel on Climate Change (IPCC) has confirmed the evident correlation between human activity and the increase of greenhouse gas (GHG) emission in the atmosphere, defining as *extremely likely* the probability that man-made emissions have been the dominant cause of climate change (IPCC, 2014). It is nowadays undisputable that the atmospheric accumulation of GHGs, and particularly carbon dioxide (CO_2), has increased significantly the total radiative forcing[1] affecting the Earth's climate, leading to a rise in the temperature of the atmosphere and the oceans, and having an impact on sea level, ice and snow amount, water and other biogeochemical cycles since the mid-20th century (IPCC, 2014). According to the IPCC, such effects would bring irreversible consequences in case the global temperature rose over two degrees Celsius above preindustrial levels (IPCC, 2014).

In light of the above, the need of a substantial and timely reduction of GHG emissions in the atmosphere is paramount. National authorities have recognised climate change as one of the biggest challenges of our times, and, as a result, many countries have pledged to curb their GHG emissions. The proliferation, in the recent years, of international treaties addressing this issue is an indicator of the growing awareness among policymakers.

In a parallel fashion, an academic debate concerning the role of private business that started to develop with Porter's *America's Green Strategy* (1991) investigated the conditions that make convenient for a firm to make environmental investments (Orsato, 2006). Stricter regulations imposed by national laws open to the possibility to gain competitive advantage and trigger innovation: firms can either choose to simply comply to the regulation or to make the most of the opportunity and develop a strategy to become environmental leaders (Porter, 1991).

A climate change mitigation strategy cannot be successful without the participation of both the public and the private sector, which need to operate in synergy to achieve a challenging results demanded by the 2 °C target. Thereby, while governments have to set ambitious goals and favourable conditions to facilitate emissions reduction through the implementation of market-based instruments and regulations coordinated by an overarching environmental strategy, private actors should be engaged in the shift to cleaner technology with active involvement in research and implementation of innovative business models.

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1 The degree to which a factor has an impact on the climate is usually evaluated in terms of radiative forcing, which is a measure indicating how the Earth-atmosphere system is influenced by a change of a climate-affecting factor. Radiative forcing is defined as the rate of energy change per unit area of the globe as measured at the top of the atmosphere (OECD, 2012).

1.1.2 The role of aviation

The aviation industry is a main contributor to economic development, accounting for over 3% of global GDP, ensuring connection among people for politics, business and tourism, supporting global trade and military defence (OECD, 2012). Trends indicate that the civil aviation sector is experiencing a rapid growth worldwide: the demand for air travel is expected to grow steadily until 2050, mostly due to the market expansion in various regions of Asia and the Middle East; increase of demand in Europe is a relevant share of this trend, accounting for 3% per year until 2050 (Biofuels Flightpath Initiative, 2013). Growth in scale, however, corresponds to an increase in aviation-generated GHG emissions, which currently account for roughly 3% of aggregate man-made emissions (OECD, 2012). Apart from CO_2, these emissions include a series of compounds such as nitrogen dioxides (NO_X), sulphur dioxide (SO_2), volatile organic compounds (VOCs), carbon monoxide (CO), black carbon (BC) and organic carbon (OC). The presence of these substances in the atmosphere generates a positive effect on the Earth's radiative forcing, which is, though, very hard to quantify, because it comprises both compounds with short-term effects and long-lasting compounds that accumulate in the atmosphere (OECD, 2012). In other words, assessing the climate impact of the emissions largely depends on the time horizon considered, although the effects are both on the short and the long term.

As discussed in the previous section, a post-Kyoto approach of international politics to climate issues has spurred the commitment towards a more sustainable economic system worldwide. This phenomenon has been observed in increasingly stringent legislation both at the national and the international scale, targeting industrial sectors to improve their environmental performances. On a global scale, the European Union (EU) and, within the Union, the country of Sweden are among the forerunners of this approach, (Kronsell, 2002; Kulessa et al., 2007; Liefferink & Andersen, 1998). However, it can be noted that, while much attention has been given to reducing GHG emissions in the overall transportation activities, the aviation sector has been largely neglected. The motive lays on the intrinsic features of the air transportation industry, a cross-national sector characterised by technological and legislative complexity, great importance for economic development, and low profits for the operating industries (B. Pearce, 2013). Nonetheless, in the recent years the reduction of aviation emissions has become part of the political agenda, to such an extent that the EU agreed to include the aviation sector in its Emission Trading Scheme (van der Heuvel, 2011).

The environmental impact of air travel depends largely on the consumption of aviation fuel (also called jet fuel in the literature). Conversely, improving the efficiency of air traffic management, aircraft and engine technologies, and air travel operations will contribute to curbing emissions only to a limited extent (ATAG, 2010; OECD, 2012). Thus, in order to achieve a carbon-neutral growth of the aviation industry it is necessary to address emissions generated by the use of jet fuel.

1.1.3 Biofuels as alternative fuels

Given the considerations presented in the previous section, an improvement of the environmental performance of jet fuels has to be achieved in order to address the climate impact of aviation.

Currently, fuels used for modern air travel are liquid hydrocarbons produced almost entirely from fossil sources (IATA, 2012). A ground-breaking innovation replacing this established technology is unlikely to come out, considering that no technological alternative to liquid jet fuels will be available in the foreseeable future (ATAG, 2011). Moreover, substituting the existing infrastructure would necessitate a long time span; this is not suitable with the aim of achieving a significant reduction of GHG emissions in a short time frame.

Thereby, a large contribution to emissions reduction can only be provided by fuels able to substitute petroleum-based fuels using the existing technology. Of the alternative fuels with similar characteristics to conventional fuels, biofuels are the only ones with a lower impact on GHG emissions (Bacovsky, 2011). Moreover, aviation biofuel (often shortened with the term *biojet* in the literature) is fully compatible with conventional technology, permitting immediate substitution to and blending with petroleum-based fuel (OECD, 2012).

Biojet is obtained from various types of biological feedstock, which consists of biomass-based resources used as raw materials. A variety of biojet production processes targeting different kinds of feedstock exists (SkyNRG, n.d.-c); an overview of these processes is presented in Table 1.

Table 1. Overview of biojet production processes.

Production process	Description	Target feedstock	ASTM certification
Fischer-Tropsch (F-T)	Conversion of any carbon-rich material via gasification into syngas, which is converted into F-T wax through catalysis and is in turn converted into jet via additional cracking.	Biomass MSW	Yes
Hydrotreated Esters and Fatty Acids (HEFA)	Conversion of oil into hydrocarbons via hydrotreatment deoxygenation and cracking.	Oils Fats	Yes
Alcohol To Jet (ATJ)	Conversion of sugars, cellulosics or syngas into alcohols, and then into jet via dehydration, oligomerisation and hydrogenation.	Biomass MSW	No
Direct Sugar to Hydro Carbons (DSHC)	Conversion of sugars and starches into intermediate hydrocarbons and upgrade into jet through oligomerisation.	Sugars	Yes
Hydrotreated Depolymerised Cellulosic Jet (HDCJ)	Direct conversion of any carbon-rich material into bio-oil via thermochemical depolymerisation and subsequent upgrade to jet through hydrotreatment and distillation.	Biomass MSW	No

Source: own elaboration, based on SkyNRG (n.d.-c).

The sustainability performance of the alternative fuel, having a crucial role for the inherent main purpose of biofuel use – emission reduction – needs to be ensured. For this reason, it is important to evaluate the feedstock and the production process in a full lifecycle perspective, accounting direct and indirect environmental impacts generated by the production of the synthetic fuel. An inadequate assessment of feedstock and fuel emissions may result in the production and use of synthetic fuels that have a worse environmental performance than fossil fuels.

Depending on the choice of feedstock and the production process, different levels of emissions reduction can be achieved. Regarding the feedstock used, a better reduction performance is achieved by biomass that does not compete with food and feed, the so-called *second-generation* feedstock, because utilisation of this type of feedstock does not cause indirect land use change (ILUC) for agricultural purposes (Rambøll, 2013). Therefore, low-emissions feedstock such as sustainable forestry products, agricultural waste, organic residues and other non-competing products should be the raw material used for biojet production. Similarly, different environmental performances are achieved by the production processes. Many aspects influence the overall process performance, including the technology used and the geographic location. Given these considerations, it can be concluded that there are numerous factors that affect overall biojet sustainability.

As discussed, only certain kinds of feedstock can be labelled as sustainable. However, a clear and globally accepted definition of feedstock sustainability is missing, due to the complexity of assessing the causation relationship between feedstock growth and indirect emission growth. As a result, studies calculating the global biomass capacity present contrasting results, depending on the sustainability criteria adopted, and the evaluation of the global bioenergy potential is still subject of debate. In other words, there is little knowledge on whether different industrial sectors will be competing for the use of biomass for transportation and energy. With this in mind, the aviation sector has a solid justification for the allocation of available biomass to biojet production, because, differently from road transport, heating and electricity, there are currently no alternatives to substitute fossil fuels.

Besides granting a lower rate of carbon emissions, the diffusion of biofuel technology is beneficial for energy security. The aviation industry has experienced a sharp rise in the price of fuel, which now accounts for over 35% of total operating costs (OECD, 2012). Given that the largest oil reserves are located in regions characterised by political unrest and unstable regimes, ensuring long term sustainability of fuel procurement is paramount (Marsh, 2008). This issue is worsened by the progressive deployment of fossil fuel resources worldwide. A study by Nygren, Aleklett, & Höök (2009) calculating a growth in global jet fuel demand of 3% per year and a decreasing jet fuel production forecasted a shortage of jet fuel supply to occur by 2026. Although this prediction should be revised in accordance with updated figures on fossil fuel reserves and the recent global economic downturn, it gives an idea on the long-term issue of resource depletion.

1.2 Problem definition and research question

On a global scale, aviation biofuels are currently undergoing their infancy phase of development process. Even though there are no technological barriers for implementation, and research and demonstration projects have achieved promising results, the diffusion of biojets progresses at a slow pace. No established supply chain is present at the moment, and the industry is striving to move from pilot plants to market-size operations. In the meantime, the number of airlines using biojet in their flights is still very limited. However, ambitious targets and regulation call for an improvement of the environmental performance of air transportation, whose reduction in carbon emissions largely depends on the employment of biojet as an alternative fuel.

Sweden is a nation that can foster biojet development, because of some of the country's deep-rooted characteristics. On a geographic level, the country is located in the Nordic region, which is characterised by the presence of many stakeholders investigating the possible developments of a market for aviation biofuel. Moreover, Swedish aviation is considered by some a necessary resource for economic development and connection both domestically and internationally. In addition, on a socio-political level, Sweden's long-term vision to establish a sustainable energy system creates a favourable environment for development. This is reflected in the strong biofuel and bioenergy use background, and in the ambition to be a world leader in cleantech innovation.

These features seem to make Sweden a country suitable for the production, use and diffusion of biofuels for aviation. However, for understanding the complex dynamics that affect biojet development it is necessary to consider the overall process of innovation creation, development and diffusion, highlighting the role of different actors and the activities they perform. By examining each player's actions it is possible to identify the key drivers and determinants for innovation success. To achieve this goal, an initial diagnostic analysis in the form of in-depth assessment of the state of play can highlight the most crucial areas for an effective and efficient development. This analysis is done through the use of the System of Innovation approach, which investigates the innovation process by describing the stakeholders in the process and the key activities they perform (or should preform).

In light of the above, the objective of this thesis project is to identify the main actors and institutions involved in the Swedish biojet innovation system, and the necessary steps to establish a regional biojet supply chain. The research will focus on mapping out the existing state of the innovation system and identifying drivers, barriers and key components for implementation and diffusion.

Given these considerations, the following research questions are posed:

1. **What is the status of the Swedish biojet innovation system?**
2. **Which drivers and barriers can be identified?**
3. **Which key components need to be established or improved for further development?**

The first and second questions aim to address the research problem in an exploratory and descriptive approach, identifying and categorising relevant system components and features. The third question tries to identify the critical existing or missing components of the innovation system, allowing to highlight the crucial actions needed to foster biojet diffusion. To achieve this purpose, an evaluative approach is used.

A secondary goal of this thesis project is to investigate the suitability of the System of Innovation framework for a practical research study. Although there is plenty of theoretical literature about System of Innovation features and categorisation methods, the amount of studies applying comprehensively the framework in a real-world context is limited. Therefore, by conducting this study, the author aims to examine the issues deriving from the application of the SI framework on an existing innovation process.

1.3 Scope and limitation

In order to increase the soundness of the research project, study boundaries shall be defined. Setting boundaries may have implications on the generalisability of results, and could preclude the understanding of complex dynamics that go beyond the area of research. However, it is important to describe the focus of research in order to provide a full picture of the areas that have (and have not) been subjected to investigation.

Due to the research focus on the Swedish innovation system, it has been decided to delimit the area of research to the national level. Although numerous key stakeholders conduct operations outside Sweden, this thesis will only focus on activities performed within the country. A series of issues arise from this choice, because certain activities (research, networking, targets setting) are greatly influenced by supranational dynamics. This influence is acknowledged and touched upon in the study, but not analysed.

The goal of the study is to describe and evaluate the biojet innovation system. Therefore, the area of focus is on the organisations and the activities that characterise the innovation system. The study does not examine in detail biojet production processes, feedstock characteristics and related technological developments, but discusses them as factors influencing the innovation process. Given that the study purpose is to give a full picture of the current state of play, the presentation of technical details will be narrowed to the understanding that different feedstock and processes exist.

Similarly, the study will give limited emphasis to sustainability issues, which are introduced and acknowledged, but not discussed comprehensively. While the debate between stakeholders over the choice of sustainability criteria is identified in the analysis, the overall sustainability performance of biojet is not examined. The study does not perform calculations of feedstock or process emissions, nor does it assess their suitability in a comparative lifecycle perspective. Effects on the environment resulting from substitution of fossil fuel with biojet are not evaluated either. Other related issues not covered in the research are concerning national (and global) current and potential biomass capacity, possible future scarcity of bioresources and competition for these resources with other energy sectors. The argument questioning the inherent sustainability and legitimacy of using air transport for short-haul travel is a major topic of debate, but does not fit with the focus of the study.

In addition to methodological choices, the study has other constrains placed upon by circumstance. A hurdle in performing research about Swedish actors and regulations is constituted by language barriers that may obstruct the process of data collection. Although language has not proved to be an issue when conducting interviews, several web resources contain inadequate information in their English version. Retrieving information from Swedish webpages generates many limitations, and might have resulted in inaccuracies.

1.4 Audience

The purpose of the study is to provide an overview of the state of play of the Swedish biojet innovation process. Identification of critical factors contributing to the success of the process are of relevance for industry stakeholders concerned about aviation sustainability, because they can steer their activities and advocacy efforts to support effectively the transition process. For the same reasons, policymakers are also part of the audience of this study. The goal of the study is to give a detail picture of what is in place and what is needed to push the transition forward. In addition, this research is of interest for the academia, because it aims to apply an established theoretical framework to a real-world setting, evaluating the performance of its practical implementation and highlighting possible areas of improvement.

1.5 Ethical considerations

It is the intention of the author to present the study in a transparent manner. For this reason, this section aims to disclose some aspects of research that would be otherwise left unclear, and to discuss some matters that may raise ethical issues.

The topic of this study has been suggested to the thesis supervisors by representatives of the Nordic Initiative for Sustainable Aviation (NISA), an association involving private and public stakeholders aiming to move forward the transition to a more sustainable aviation in the Nordic region. Although the collaboration between NISA and the author has been at a rather informal level and mainly consisted in the support to the process of identifying and contacting stakeholders, it is important for transparent disclosure of information to point out how the research project originated. Definition of the thesis focus and conduction of research are activities that have been carried out independently, and no external funding was received. The preliminary results of this work have been presented at the Green Aviation Days conference in September 2014 in Copenhagen organised by NISA. The association aims to use the thesis results as a baseline for the conduction of a Nordic study on biojet potential.

Another issue worth discussing is concerning this study as a research providing benefits to the environment. The fact that the EMP Master Programme aims to study the means of developing a sustainable economic system might raise the question of the legitimacy of a research aiming to optimise the aviation sector environmental impact, but not addressing the question of intrinsic sustainability of aviation. It can be argued that the modern transportation sector is unsustainable and profound modifications in its core features are needed. These relate to a change in technology, logistics, attitudes, behaviour, and, in general, society. The validity of this idea is recognised by the author. However, while acknowledging the need of a radical change, it is believed that intermediate steps towards a greener economic system will facilitate this process, providing incentives for further social and technological improvements and increasing the awareness among the public.

1.6 Disposition

Chapter 1 presents an introduction to the research study. The provided background information explains the significance of the study. In addition, the research problem is defined and addressed.

The methodological framework for analysis is described in Chapter 2, where existing literature is analysed and a customised framework is developed and described. The Chapter also present methodological choices and means of data collection and analysis.

The system diagnostic analysis is performed in Chapter 3. As each system category is investigated and evaluated, this section represents the bulk of the text.

The discussion provided in Chapter 4 conducts an overall evaluation of the research. Results are interpreted and commented, and their significance examined. Moreover, various aspects that affected the study results – methodological choices, framework suitability – are analysed, leading to some considerations on study significance, replicability and validity.

Lastly, Chapter 5 summarises the study results and indicates observed data gaps that necessitate further research.

2 Methodology

The purpose of this Chapter is to illustrate in which way the research has been conducted, and the process that lead to the choice of the conceptual framework used. Thus, a first section will describe methodological choices regarding types of sources and data collection methods. Secondly, a general overview of suitable frameworks will be presented. The discussion leads to the description of the model utilised in the study, the Innovation System framework, with an in-depth analysis of the framework components.

2.1 Methodological approach

The study follows a qualitative approach for presenting the system constituents and describing their characteristics and activities. Collection of such information has been mainly done through the analysis of secondary sources, most notably grey literature such as company reports and their online resources. Peer-reviewed literature has been also consulted in order to retrieve information regarding biofuel economics and national or international trends, comparison between different market-based policies and assessment of their effectiveness, and innovation system theory. In addition, useful data about aviation and biofuel trends has been collected from official reports from governmental agencies and non-governmental organisations.

Secondary data has been integrated with primary data retrieved through the conduction of 18 structured and semi-structured interviews with relevant stakeholders in the Swedish region. A full list of interviews can be found in the Appendix. The interviews added substantial value to the research since they allowed to gather information that would not have been found in other sources. This includes information about collaboration activities, stakeholders' benefits for participating in joint projects, the underlying reasons of specific policies design, unstated intrinsic issues for development, and many others. Interviews also contributed in identifying and getting in contact with relevant actors that would have otherwise been overlooked. It has been deemed appropriate to combine the use of primary and secondary data in order to extend the coverage of the study to different types of issues that would not have been comprehensively assessed without the utilisation of a bidimensional approach.

2.2 Analytical framework

This research aims to define the progress of implementation of an innovative technology – biofuels – in the Swedish aviation sector. The use of bioresources to run airplanes is at the early development phase, and in order to diffuse and utilise this technology several conditions have to be met. To identify the stakeholders involved in the innovation process and the factors that hamper or foster technological development it is necessary to consider the whole constellation of actors and relations that have an impact on the innovation process. A few methods for analysis of the innovation process will now be presented.

Research and development activities are paramount for the development of a new technology. Therefore, it is important to examine the relationship between firms operating in the market and research initiatives to have a better understanding of the innovation process. To analyse the collaboration between enterprises and research bodies such as universities and research institutes, three approaches have been identified: the Mode 2 Knowledge Production, the Triple Helix, and the System of Innovation.

The Mode 2 Knowledge Production thrusts for interdisciplinary, objective-based research, as opposed to research motivated solely by scientific knowledge. Therefore, the framework promotes the production of knowledge in the context of its application, identifying key features to be implemented (Brundenius, Göransson, & Ågren, 2011). Though Mode 2 has been a source of inspiration for innovation analysis, it performs a less comprehensive investigation than other methods, and has therefore not been applied.

According to the Triple Helix framework, three main actors have an impact on the innovation process: university, industry and government. Differently from similar frameworks, particular emphasis is given to the role of universities, which play a prominent part in the innovation process (Brundenius et al., 2011). This method has valuable insights for analysis, but does not utterly suit the purposed research because the focus of the study is set on university research.

Both the Mode 2 and the Triple Helix framework address the topic of innovation in a theoretical perspective, but give no indication on how an existing innovation process could be analysed. With this regard, it is interesting to discuss a third approach for assessing innovation, the System of Innovation (SI) theory. The basic assumption of the SI approach is that the determinants of technological change are not only the firms directly involved in the innovation process, but the entire social structure that surrounds their activities (Suurs & Hekkert, 2009a). Unlike the two other approaches, this method gives a broad picture of the relationships among the stakeholders and their activities, and enables to perform a diagnostic analysis of the key components of the system, pinpointing systemic weaknesses and areas requiring intervention (Edquist, 2011).

The SI conceptual framework has been chosen for performing this study. Apart from the features already mentioned, this approach has several advantages. Firstly, the broad system analysis is complemented by an interdisciplinary perspective that takes into consideration organisational, political, social and economic aspects (Edquist, 2005). Secondly, this approach is characterised by a historical and evolutionary perspective, which grasps the dynamics of technological innovation (Edquist, 2005); notably, recent studies have deepened the analysis of this feature of SIs (Suurs & Hekkert, 2009a, 2009b). Thirdly, the SI approach is particularly suitable for the analysis of sustainability innovations, especially in relation to technological systems of innovation, which is the case for aviation biofuels (Suurs & Hekkert, 2009b). Fourthly, emphasis is given to systemic interdependence and feedback loops that can be used as a leverage for enhancing the innovation process (Edquist, 2005). Fifthly, differently from other methodological approaches, a central role in SI analysis is played by institutions (Edquist, 2005). This feature is particularly relevant in the biojet innovation process, whose success is highly correlated to system institutions. This aspect will be further examined later in this Chapter, with the provision of concept definitions.

2.3 System of Innovation

Although the concept of "system" has been used for a long time in many different applications (Dahmén, 1988; Leontief, 1941; Meadows, 2008), and its application to innovation had already been observed by Friedrich List in the XIX century, a modern approach to innovation systems started to develop in the 1980s with some highly influential publications by Freeman (1987), Lundvall (1988, 1992), Nelson (1988, 1993), and others (Carlsson, Jacobsson, Holmén, & Rickne, 2002; Edquist, 1997; Freeman, 1995). Describing the characteristics of "National Systems of Innovation", the authors categorised the roles performed by firms and other organisations, their activities for the diffusion of new technologies, and the linkages between different actors, in order to foster innovation (Carlsson et al., 2002). These works caught the interest of a great number of scholars which expanded the academic research on the field and made the System of Innovation framework widely diffused (Edquist, 2005). Since the concept deals with a broad system characterised by complex dynamics, research on SIs has unfolded many different approaches through time – national, sectoral/technological, regional, according to the area of focus; but also theoretically oriented or based on case studies, according to methodological choices (Edquist, 1997). However, having numerous aspects in common, it can be argued that these approaches are variants of the same conceptual framework addressing the research in different perspectives that complement each other (Edquist, 1997).

A review of the existing literature on SIs shows a general lack of universally accepted definitions, due to the various approaches used and the amount of existing material. Another reason to explain the presence of what Edquist (2005) calls "conceptual diffuseness" in SI definitions is the ambiguity of some terms used in the literature that are given diverse meanings from different authors. A result of this phenomenon is the existence of several synonyms to indicate components, activities, features and relations among the innovation system. To overcome this problem, these characteristics have to be defined.

According to the work of Ingelstam (2002), a system is constituted of: a) its components, and the relations among them; b) a function or purpose; c) some boundaries that delimit the system area. In a SI, the main function is to pursue innovation processes, that is to develop, diffuse and use innovations (Edquist, 2005). Thereby, the system components are identified as all the important factors that influence and contribute to the innovation process (Edquist, 1997). Components are organisations ("players of the game", actors with a specific purpose) and institutions ("rules of the game" that regulate the relations among the actors) (Edquist, 2005). Lastly, the boundaries of the system may vary according to the type of focus. A national system of innovation comprises all the actors that play a role in the innovation process at the national level. Previous studies on the biofuel innovation system argue that technology dynamics are country-specific (Suurs & Hekkert, 2009a, 2009b); this validates the utilisation of the national borders as a system boundary.

A system conceptual representation is presented in Figure 1.

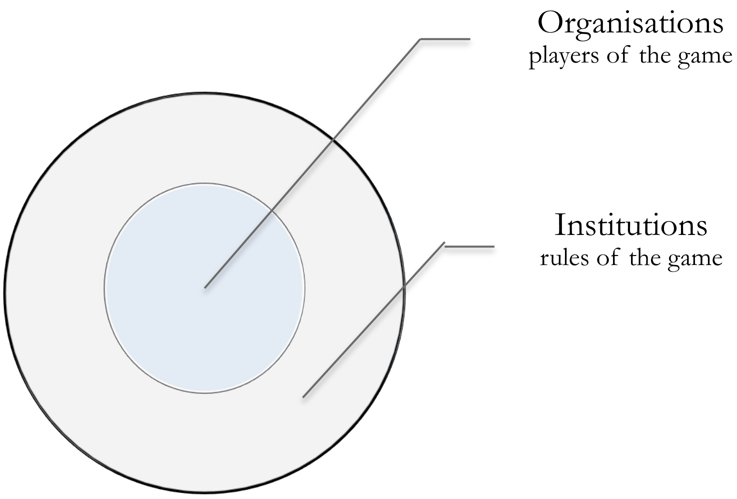

Figure 1. System conceptual representation.

Source: own elaboration.

Clearly, alternative categorisation of system features exist, such as in Carlsson et al. (2002), in which the terms *components*, *relationships*, and *attributes* are used. However, it can be noted that many definitions resemble the ones presented in the previous paragraph, and usually different terms are synonyms of the same concept.

Given that the overall function of the SI is to develop, diffuse and use innovation, it is important to identify which activities, or system functions, must be undertaken for fulfilling the system purpose. Therefore, these activities are the causes or determinants of the development, diffusion and use of innovation (Edquist, 2011). Regardless of the similarities in system definitions, authors have developed different methods to categorise the key activities in a SI (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008; Bergek & Jacobsson, 2003; Edquist, 2005; Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007; Liu & White, 2001; Rickne, 2000). An overview of different approaches can be found in Chaminade & Edquist (2006). Three categorisations that have been deemed relevant for the purpose of this study are presented in Table 2.

It can be noted that the methods have differences and similarities, even though it is claimed that they largely enclose the same processes (Jacobsson & Bergek, 2011). The categorisation provided by Edquist (2005) is focused on the activities connected to the innovation process, that is, the activities needed to turn an idea into a new product or process. Ten key activities, structured into four thematic groups, are defined. This approach will be used as a general guideline for identifying the key activities of the biojet SI.

Table 2. Key activities categorisation methods

Edquist (2005)	Hekkert et al. (2007)	Bergek et al. (2008)
(I). Provision of knowledge inputs to the innovation process 1. Provision of R&D results 2. Competence building **(II). Demand-side activities** 3. Formation of new product markets 4. Articulation of new product quality requirements **(III). Provision of constituents of SIs** 5. Creation and change of organisations 6. Networking 7. Creation and change of institutions **(IV). Support services for innovating firms** 8. Incubation activities 9. Financing of innovation processes 10. Provision of consultancy services	**1. Entrepreneurial activities** **2. Knowledge development** **3. Knowledge diffusion** **4. Guidance of the search** **5. Market formation** **6. Resource mobilisation** **7. Support from advocacy activities**	**1. Knowledge development and diffusion** **2. Entrepreneurial experimentation** **3. Influence on the direction of search** **4. Resource mobilisation** **5. Market formation** **6. Legitimation** **7. Development of positive externalities**

Source: own elaboration, based on Bergek et al. (2008); Edquist (2005); Hekkert et al. (2007).

Other authors have identified different classifications of activities in accordance to their research objectives (Chaminade & Edquist, 2006). What is underlined in many of these works is the importance of tailoring the classification methods to each research project, since the groups of activities are not fixed but rather flexible. The groups boundaries are not fully defined and shall be customised according to the specifics of the SI studied. Likewise, some groups of activities might be less important in a system but highly relevant in another (Edquist, 2005).

In light of the above, it has been necessary to recognise which activity groups are relevant and applicable to the biojet SI and which ones are negligible. Using the Edquist model as a baseline, it has been decided to remove three categories: *2. Competence building*, *8. Incubation activities*, and *10. Provision of consultancy services*. The exclusion of these activities is related to the subordinate importance that they have on the biojet SI; this aspect will be scrutinised and further justified in sections 2.3.1 and 2.3.4. However, this does not imply that these activities will be overlooked, but that any useful finding regarding them will be included in other suitable groups.

In the next sections, each of the thematic groups used for analysis is described. The four thematic groups are *Knowledge inputs*, *Demand-side activities*, *System constituents* and *Support services*. Information includes the content of each thematic group and key activities group, its contribution to the system function, examples of typical activities and the extent to which the group will be examined.

2.3.1 Knowledge inputs

Information, knowledge and learning are a fundamental prerequisite for the innovation process; their importance has been pointed out by several SI academics (Edquist, 2011; Hekkert et al., 2007; Lundvall, 1992). Comprised in the *Knowledge inputs* group are all the activities performed to strengthen and deepen the knowledge base. The main activity group belonging to this area is *R&D results*. Research and experimental development can be divided into three main blocks: basic research, which is theoretical work with no particular application in mind; applied research, investigating means to achieve a practical objective; experimental development, using research findings for the development of a new product, service, system or process (OECD, 2002). Research and development activities presented in this group are related to applied research and experimental development rather than basic research. R&D is performed by both the public and private sector, although one should note that in Sweden much of this research is carried out by private organisations with strong financial support from the state (Edquist, 2011). Thereby, particular focus will be given to private research initiatives and joint private-public projects. Typical activities in this field are applied research initiatives in universities, pilot projects for demonstration, collaborations with international research projects.

The other activity group belonging to this thematic area, *Competence building*, has a subordinate role in the biojet SI, since individual learning and competence transfer within actors are not central elements in biofuel technology development. For instance, a factor like skilled labour is more suitable for more traditional innovation processes. However, some other activities (such as sharing of information among high-level researchers) can contribute to the innovation process, and will be discussed in the study. Such information will be included in the two most suitable groups: *R&D results* and *Networking*.

2.3.2 Demand-side activities

This thematic area aims to describe the efforts to stimulate the development and diffusion of biojets from the demand side. Clearly, the production and supply of biofuels cannot be provided without a parallel expansion in the demand of these products. Activities in this area are performed for creating and consolidating the new market.

Most of the key activities from the demand side belong to the *New product markets* group. This group aims to examine the activities performed for the creation and development of the biojet market and to assess its current stage of progress. Such activities include the initiatives started by the aviation industry, public authorities and NGOs trying to increase the use of biofuels for air transportation. In the case of biofuel deployment, typical activities are the introduction of quota obligations or setting new environmental targets. Organisations are steered by different drivers to expand the biojet market: in this section the rationales behind a push for larger use of biofuels will be examined.

Another important set of operations that have an impact on market formation is related to advocacy and legitimation activities performed by various actors in the SI. Even though this series of activities does not belong to the original Edquist model, it has been noted its significance in the biojet SI, which is deeply affected by public policy decisions. Considering that numerous approaches from other authors comprise a group of activities related to advocacy (Bergek et al., 2008; Hekkert et al., 2007), the original model has been adapted to this need. As a result, legitimation and lobbying efforts are included in the *New product market* activity group.

Activities related to the implementation and change of national and international biofuel quality standards (e.g., determining the sustainability of a product in relation to its indirect land use change) also affect the performance innovation process. Thus, a separate group of key activities named *Quality requirements* will be discussed in this thematic area. The demand for quality requirements can come from different stakeholders. Public authorities can also have an impact on defining standards, obliging the industry to conform to national or international regulation.

2.3.3 System constituents

System constituents represent the core of any SI, and perform the bulk of the activities that determine its success. SI constituents include organisations (the actors), networks (the interactions between the actors), and institutions (the rules under which the actors operate) (Edquist, 2005; Ingelstam, 2002). This subdivision is used for the identification and description of the key activity groups.

The first activity group in this thematic area is *Organisations*. Without the contribute of organisations operating in the SI, there cannot be any innovation process. The term organisation reflects all the actors having a role in the development and diffusion of biojet technology. The group includes private and state-owned companies, public authorities, universities, research institutes, financing bodies, NGOs, and so on. Individuals are by all means actors in the game, but they usually belong to larger groups of stakeholders. In addition, it can be the case that a single person belongs to or collaborates with more than one organisation. For the sake of clarification, individuals will not be considered as organisations.

To assess the development of the SI in a dynamic perspective it is necessary to observe the creation of new organisations, as well as the change of incumbent actors. This is the original approach in the Edquist model. However, in order to give a snapshot of the level of progress in the innovation process, the dynamic perspective is not sufficient. For the purpose of this study it has been decided to include a description of the organisations operating in the biojet SI and their related activities. Additionally, this section will try to assess the role of organisations that could potentially be involved in the SI but are not currently performing any activities. Identification of potential actors might prove to be problematic; some reflections with this regard will be included in the Discussion Chapter.

The second activity group is *Networking*. A basic principle of SI theory is that the interactions among system components affect greatly the success of the innovation process. The group comprises these non-linear features of the innovation process and describes how different actors and institutions relate to each other. The most notable results of these interactions are reflected in the founding of network groups and other forms of collaboration within actors. However, to identify and describe all the interactions among system components is a challenging task. Particularly problematic is to recognise the forms of informal collaboration that are embedded in a national culture or a sectoral environment. While informal interactions have to be ruled out of the study, a discussion about rules, norms and costumes is included in the next group.

The third group, *Institutions*, describes the activities related to the creation and change of the "rules of the game". They include all sets of common habits, norms, routines, established practices, rules and laws that regulate the relations and interactions between individuals and organisations in the system (Edquist & Johnson, 1997, p. 46). Institutions set the environment in which organisations operate; this environment, however, is dynamic and can be subject to change. Modification of the rules that regulate the interactions among the actors can have a remarkable effect on the success of the innovation process, and the presence or absence of some institutions can be a critical factor for success or failure.

Institutions play a prominent role in the aviation biofuel SI. One example is environmental legislation: regulation that provides long-term commitment to cleaner transportation can create stability in the market and encourage organisations to invest on innovative biofuel technology; a dull approach to sustainability issues for fuels leaves the initiative of technological switch to firms and NGOs.

Institutions are present in the SI on several levels. Some of them are deeply rooted within the system and are difficult to change, either because they are operating from an overarching level (e.g., European laws) or because there are mental barriers embedded within the actors (e.g., cultural beliefs and social norms). It is required to distinguish between institutions that can be changed in the short term and institutions that can be transformed only with large efforts over a long period. As for networking activities, detecting and discussing informal institutions embedded in the system proves to be a difficult task, whereas official institutions such as European and national laws and regulations are easier to identify, and will be discussed comprehensively.

2.3.4 Support services

The fourth thematic area comprises the activities that facilitate the innovation process through the provision of support services. These services can deliver material and non-material help to organisations of the SI. Material support consists for example of financial assistance in initial capital raising and ensuring product competitiveness, or access to facilities for R&D initiatives;

non-material support relates to provision of knowledge and consultancy services, administrative assistance, legal advice.

The biojet SI is characterised by the presence of large firms that do not need support services such as legal advice and administrative assistance because they have internal capacity to handle these matters. For these actors, the importance of incubation activities and consultancy services is secondary. For this reason it has been decided to rule out of the scope of the study the support services that do not have significant relevance for the system organisations, and to exclude the *Incubation activities* and *Provision of consultancy services* groups from the system analysis. Activities related to these groups that have an impact on the success of the innovation process will be included in other suitable categories.

The only activity group belonging to this thematic area is therefore *Financing of the innovation process*. Activities dealing with provision of financial support to innovating firms are crucial for kick-starting the commercialisation of innovation ideas and supporting their deployment.

Provision of financial capital is usually performed by private funding within the firms, venture capital funds and firms, banks, business angels and public funding. Initial capital raising for investment is certainly an important feature in the biojet SI, but even more critical is safeguarding its long-term economic performance. Indeed, the most crucial (and challenging) financing issue in this system of innovation is to ensure market competitiveness at the early stage, that is, to make biojet an economically feasible alternative to conventional fuel production and use. When an innovative product is not cost-competitive, allocation of public funds in the form of subsidies is measure to encourage investments in a long-term perspective and to reduce uncertainty. Complementarily, the government can impose taxes and fees to finance these operations and level the playing field. Given these considerations, an important share of financing activities will be coming from public financing operations.

2.3.5 Additional remarks and framework overview

Complementary to the introductory observations discussed when presenting the SI model, a few additional reflections about the utilisation of this conceptual framework have to be made.

A noteworthy consideration to make is regarding the group division: the Edquist model does not define a clear cut between the activity groups, inducing an overlapping of activities among various groups. For instance, creation and change of intellectual property rights is presented as both a demand-side activity and as an institution-related process. The group division applied in this study will adhere to the group definitions presented in the previous sections. While being aware that giving more precise definitions of the group boundaries creates a discrepancy from the original group division, one should recognise that it is an essential procedure for a better understanding of the research findings.

A similar observation regards the belonging of some activities to different groups, depending on the perspective considered. National environmental legislation indicates the regulations under which organisations have to work, and so is comprised in *Institutions*, but can also influence the creation of a new market when setting environmental targets for renewable fuels, and should therefore be included in *New product markets*. Allocation of subsidies or tax relief to renewable fuels is part of the environmental legislation, but is an activity connected to financing matters. Again, information will be discussed attaining to the group definitions previously provided, and different aspects of the same activity will be presented separately.

Defining the degree to which actors should be included in *Organisations* rather than in the group that contains their core activities is also problematic. For instance, a financial institution is indeed a system organisation, but its core activities are predominantly related to financing issues. In order to avoid repetition, actors that do not play a central role in the innovation process and are interacting in a univocal dimension with the system (e.g., only providing financial services) will not be included in *Organisations*.

A final consideration concerns the interconnections between the groups. All the groups are interacting among each other, and a change in one can cause large effects on another. However, to assess such causation relations is outside the scope of this research, therefore the study will restrict itself to describe group activities separately. Some considerations with this regard are presented in section 4.2.

To conclude the discussion over the methodological approach, the conceptual framework used for the analysis is presented in Table 3. The framework includes the four thematic areas described in the Edquist model, and seven groups of key activities that characterise each area. In addition, a series of questions relating to each group of activities is provided, according to the group descriptions that have been presented in the previous sections. The purpose of these questions is to provide a guideline for research and to steer the process of retrieving information towards relevant topics. In other words, the questions give a general indication of the main issues covered by each activity group.

Even though the amount of questions posed might look too large, it should be noted that this research aims to perform a diagnostic analysis of the SI, and is therefore legitimate to have a broad research focus. An implication of this broad structure is that not all the questions now posed will be fully answered, but they will be rather considered as potential areas for investigation.

It has been stated that the study intends to perform a diagnostic analysis of the innovation process. Before proceeding with the analysis, however, it is important to clarify what this concept means. As discussed by Edquist (2011b), a diagnostic analysis aims to understand systemic problems in the innovation process. This goal is accomplished in three steps: firstly, by evaluating the performance of the overall innovation system and assessing its problems; secondly, by identifying the causes of these problems; thirdly, by analysing the problems through the review of the SI key activities.

Table 3. Conceptual framework.

Thematic area	Key activity group	Guideline questions
Knowledge inputs	**1. R&D results**	Which organisations are involved in R&D activities? What is being researched? Which pilot and demonstration projects have been launched?
Demand-side activities	**2. New product markets**	What are the activities performed for creating and developing the biojet market on the demand side? Which organisations perform such activities? What are the drivers that steer organisations for expanding the biojet market? Which advocacy and legitimation activities are performed? Which organisations are performing such activities?
	3. Quality requirements	Which biofuel quality requirements have been set? Which organisations are responsible for setting standards and requirements?
System constituents	**4. Organisations**	Which organisations are currently operating in the biojet SI? Which core activities do they perform? Which organisations could be involved in the biojet SI in the future? Which activities would they perform?
	5. Networking	Which networking activities are currently in place? Which forms of informal collaboration are being performed?
	6. Institutions	Which institutions are currently operating in the biojet SI? To which activities do they relate? Which organisations are involved in the creation and change of institutions?
Support services	**7. Financing of the innovation process**	Which forms of financial support are currently in place to ensure initial capital raising? Which forms of financial support are currently in place to ensure early stage market competitiveness? Which organisations provide these two types of financial support, respectively?

Source: own elaboration.

3 Diagnostic analysis

3.1 Knowledge inputs

3.1.1 R&D results

In parallel to the large deployment of bioenergy use for heating and transportation purposes on the national territory that occurred since the 1980s, Sweden has been till date one of the countries leading the way in biofuel research (Humalisto, 2014; Negro, Alkemade, & Hekkert, 2012). Apart from the need to perform research in order to foster the diffusion of bioenergy technology in the national area, this leadership is due to several inherent factors, including a strong support to research from the state and the country's long tradition of research excellence. Consequently, a number of actors performing research in the bioenergy field exist. Since the research topics involve a high level of complexity, an important contribution to delivering R&D results is given by joint research activities characterised by collaboration between actors with different areas of expertise.

Biofuel networks

A significant share of research activities that relate to biojet is promoted by biofuel research groups, whose area of interest generally covers the entire transportation industry rather than only the aviation sector. These include the f3 centre, the bioenergy clusters in Northern Sweden, Svebio, and others. Research activities performed by such groups may not focus specifically on aviation biofuels, but even so they can provide knowledge that indirectly benefits the development of biojet diffusion. Some of the most relevant groups will be now presented, and the extent to which biojet-specific research activities are performed will be discussed.

The f3 centre (Swedish Knowledge Centre for Renewable Transportation Fuels; in Swedish: *Svenskt kunskapscentrum för förnybara drivmedel*) facilitates research activities contributing to the development of environmentally, economically and socially sustainable renewable transportation fuels (f3, n.d.-a). The centre started its activities in 2010, and it is a uniquely broad partner group: among its members there are several Swedish universities, industry companies, research institutes and public entities. The collaboration with universities such as KTH, Lund University, Chalmers University and Linköping University has a particular relevance since it gives a strong academic basis to the centre activities (f3, personal communication, 2014). All f3 partners are involved in R&D activities, either contributing financially or conducting research in cooperation with the other partners involved in each project. Industries are mainly interested in getting concrete results, and are often directly involved in research projects. Universities and research institutes, on the other hand, benefit from the partnership by using the allocated funds to conduct research and by receiving information about the priorities set by the industry (f3, pers. comm., 2014).

Research has a general focus, hence not on specific fuels or technologies but rather on the overall topic of renewable transportation, and a systemic approach is applied (f3, pers. comm., 2014). Support to research is given through interdisciplinary collaboration, networking, communication activities for knowledge dissemination, and, most importantly, R&D projects (f3, n.d.-b). Each project carried out by the f3 centre falls within one of the following area categories: (a) comprehensive technological, economic and/or environmental system studies; (b) stakeholder, policy and strategy studies; (c) comparative system studies of alternative process chains; (d) studies on process integration and efficiency improvement potentials; (e) syntheses of current knowledge status for specific areas or surrounding conditions of the value chain (f3, n.d.-b). All projects relate to one of the steps of the biofuel value chain – raw material, production and use (f3, n.d.-b).

The projects are mainly financed by the program *Förnybara drivmedel och system* (Renewable transportation fuels and system) promoted by the Swedish Energy Agency (STEM). The program will run during the period 2014-2017, providing funds for 44 million SEK (4,8 million EUR[2]) (STEM, 2014). Project deliverables compiled upon the termination of the project are official reports in which the findings of research are presented. Representatives of the f3 centre argue that, despite the projects are backed by a significant allocation of resources, research activities directly connected with aviation biofuels have been minimal (f3, pers. comm., 2014). The procedure for starting a project requires members to send a research proposal application; it is claimed that the lack of research in relation to biojet is because members have not submitted any aviation-specific research proposal (f3, pers. comm., 2014). In other words, some member should express its interest towards biojet technology to start research on the area. However, it should be noted that there are numerous projects that are indirectly interesting for aviation biofuels (f3, pers. comm., 2014). Even though the focus on biojet is scarce at the national level, the interest towards this technology is growing on the international scale. There are several European groups conducting studies in this direction, such as the IIASA institute in Austria. Part of f3 future strategy is to identify and establish contacts with these international organisations in order to improve networking and joint research activities, ensuring improved results in view of the 2020 target (f3, pers. comm., 2014).

Bioenergy research is particularly strong in northern Sweden, with a wide range of actors such as universities (Umeå University, Luleå University of Technology) and research institutes (Energy Technology Centre, or ETC), which, together with public authorities and firms, form an important bioenergy hub. The actors are interconnected through a series of platforms and initiatives that generate a dynamic research environment; the number of initiatives and actors involved is remarkable. Examples of this very active research cluster are the *Bio4Energy* network and the *Biorefinery of the Future* initiative, both promoting biorefinery studies and collaboration among the partners with the support of public funding. An important public body involved in this process is Formas, a governmental, tax-financed agency promoting research through the allocation of funds to eligible applicants in the fields of environment, agricultural sciences and spatial planning (Formas, 2014). Most of these initiatives investigate biomass utilisation for traditional consumption areas – heating and road transport. Nonetheless, research activity focusing on gasification processes is relevant for the aviation sector, because in the last step of the process it is possible to produce biofuel (f3, pers. comm., 2014). Concerning gasification processes, another joint project is the SFC (Swedish Gasification Centre), coordinated by Luleå University in collaboration with Chalmers University, KTH and ETC. The centre spurs collaboration among the partners and looks for synergies among different technologies (Lund University, pers. comm., 2014). Research activities have a ten-years budget of 540 million SEK (58,6 million EUR), with financial support provided by STEM, the academia and the industry (Luleå University, 2011).

Svebio, the Swedish Bioenergy Association, is an industrial NGO aiming to develop bioenergy in an economic and sustainable way (Svebio, pers. comm., 2014). The group consists of over 300 associates including enterprises, consultants, politicians and private members, and its core activities relate to knowledge dissemination and advocacy (Svebio, n.d.). The association's efforts in R&D activities are reflected in the involvement in many research platforms and

[2] SEK values have been converted in EUR values on date September 11, 2014. The values are approximate.

networks. Svebio is not participating in any specific research project, but contributes to research as a data gatherer (Svebio, pers. comm., 2014). In order to provide information for research projects, many investigations to identify the amount of biomass available for transportation purposes have been carried out (Svebio, pers. comm., 2014). Svebio claims that, thanks to the investigations conducted, Sweden is one of the countries in Europe with the most detailed information about its feedstock availability (Svebio, pers. comm., 2014). Results from these studies indicate that there is a significant amount of feedback that can support further bioenergy development (Svebio, pers. comm., 2014). Production capacity of forest biomass has been thoroughly studied, whereas production capacity of biomass derived from agricultural land is harder to assess. Other than being a partner in research platforms, the association is the initiator of various activities related to biofuel promotion and diffusion, creating an environment where organisations are brought together and can start collaborating. An example of this kind of activities is the World Bioenergy conference, hosted in Jönköping every year and gathering experts from all over the world.

Not unlike the bioenergy groups previously described, Svebio has limited focus on aviation biofuels. The reason once again is the scarce interest from the association members, who give priority to more conventional uses of bioresources (Svebio, pers. comm., 2014). Of late, however, it seems that the trend is changing, due to the rapid expansion of the aviation sector in the biofuel environment (Svebio, pers. comm., 2014).

As discussed, many enterprises belonging to the bioenergy cluster participate in R&D activities within broad research networks. These collaborations are characterised by an open innovation approach in which knowledge is shared and joint efforts result in improved performances. Companies working with aviation biofuels conduct some of their R&D projects in Sweden. To provide an example, the Dutch biojet provider SkyNRG is active in R&D operations and has launched collaboration projects with various Swedish actors. One of these projects, organised in cooperation with the company Swedish Biofuels AB, aims to convert ethanol to biojet and to set demonstration flights (SkyNRG, pers. comm., 2014).

Academic institutions

It can be noted that research groups are characterised by circular connections among the actors involved. Through the joint research initiatives producers obtain financial support from STEM, which provides funds for start-up projects and innovative research.

While the importance of the joint research activities should not be underestimated, it is also relevant to point out that actors within the bioenergy research groups have their own research projects. Universities play a central role in this process; a few research initiatives from universities in Sweden will be now presented.

A world leader in research on biofuel production is Lund University, thanks to a tradition of 30 years of bioenergy research. An important area of research is regarding the production of 2^{nd} generation ethanol (Lund University, pers. comm., 2014). Lately, there has been an increased focus and many studies on biochemical conversion technology, which is of interest for the aviation sector (f3, pers. comm., 2014). Additionally, a relevant area of study is related to feedstock alternatives in a system perspective (Lund University, pers. comm., 2014).

Another hub for system analysis is Chalmers University, where broad system studies on transportation and environment are performed: global-scale system studies on the impact of a carbon-neutral transportation, as well as local system studies focused on Sweden. National studies, however, analyse road transportation and neglect the aviation sector. This is partly due to the predominance and development of the Swedish road transportation industry (f3, pers.

comm., 2014). System studies investigate the issue of fuel sustainability and compare different feedstocks that could be used as bioresources for producing biofuel.

In Luleå University, studies about different kinds of fuels, chemicals and their potential applications are being conducted (f3, pers. comm., 2014). Research is primarily focusing on Dimethyl ether (DME), a second-generation biofuel that results from gasification processes (f3, pers. comm., 2014).

As a general trend, studies assessing the feasibility of various materials and chemicals are being conducted, with the goal of examining the possible kinds of fuel that can be produced (f3, pers. comm., 2014). This type of research is very diffused in the academia. Current research is also assessing the efficiency of new bioenergy technologies in terms of logistics. Several examples and pilot tests have been showing that new technology can economically compete with established methods, and it would be commercially interesting to see new plants with alternative logistic solutions. However, new technology has often not been implemented because of the costs of substituting the existing infrastructure (Lund University, pers. comm., 2014).

Aviation industry

In general terms, it can be observed that the extent to which actors from the aviation sector participate to national-level research activities is limited. One of the few actors involved in these activities is Scandinavian Airlines (SAS), which, although does not conduct any actual research operations, contributes to several R&D initiatives as a supporting partner (SAS, pers. comm., 2014). Contracts negotiated with research partners define the company's involvement through provision of financial capital, technological knowledge and resources (SAS, pers. comm., 2014). As a company with a focus on the Nordic region, SAS supports additional research and demonstration projects in Norway and Denmark (SAS, pers. comm., 2014).

Conversely, various initiatives are performed at the European and international scale. These involve the participation of large airline companies, or airline associations, as representatives of the air travel industry. Several international research groups and initiatives exist; a compendium of them is presented in Table 4.

Table 4. International research initiatives.

International Civil Aviation Organisation (ICAO): a UN civil aviation agency with the tasks of setting standards and regulations for aviation safety, security, efficiency, regularity and environmental protection (Bacovsky, 2011). ICAO's Alternative Fuel Task Force (AFTF) conducts research on carbon emissions reduction potential derived from the use of biojet. ICAO provides an updated list of biojet-related activities worldwide, consultable on the agency's webpage, named Sustainable Alternative Aviation Fuels Activity (SAAFA). Moreover, ICAO has developed a database of R&D activities in the field, called Global Framework for Aviation Alternative Fuels (GFAAF). ICAO and its activities will be further analysed in section 3.3.1.
Advisory Council for Aeronautics Research in Europe (ACARE): a European project involving the EC, European member states, industry stakeholders, and the academia. ACARE has its main focus on setting the research agenda in Europe in accordance with the Vision 2020 (Bacovsky, 2011). A report, *Flightpath 2050,* defines Europe's vision for aviation.

Sustainable Way for Alternative Fuels and Energy for Aviation (SWAFEA): a study for the EC to investigate the feasibility and the impact of using alternative fuels in aviation (Bacovsky, 2011). The project includes several actors in the aviation, together with fuel and biofuel industries.
Alternative Fuels and Biofuels for Aircraft Development (Alfa-Bird): a research initiative, co-funded by the EU, with the goal of investigating and developing alternative fuels for aviation. Alfa-Bird enjoys the participation of a wide range of stakeholders (Bacovsky, 2011).
European Advanced Biofuels Flightpath: an initiative involving the European Commission, the aviation industry and biofuel producers aiming to foster the commercialisation of aviation biofuels in Europe (Bacovsky, 2011).
European Biofuels Technology Platform (EBTP): a private-public partnership bringing together the European authority and various stakeholders, contributing to the development and commercialisation of biofuels in the EU through promotion of research, technology development and demonstration projects (Bacovsky, 2011). The Initiative Towards Sustainable Kerosene for Aviation (ITAKA) is a collaborative industrial project connected to EBTP with the aim to contribute to short-term EU objectives on aviation by supporting research and development projects (ITAKA, n.d.).
Sustainable Aviation Fuel Users Group (SAFUG): an international airline and manufacturer association aiming to accelerate the development and commercialisation of sustainable biojet in light of the 2020 targets. The group is backed and advised by international environmental NGOs such as the Natural Resources Defence Council and the Roundtable of Sustainable Biomaterials (SAFUG, 2014)
Commercial Aviation Alternative Fuels Initiative (CAAFI): an North American initiative supported by the public and private sector with the aim to enhance energy security and sustainability of aviation through the development and deployment of alternative fuels (Bacovsky, 2011). The initiative facilitates the exchange of information and knowledge through organisation of workshops and advocacy activities.
Aviation Initiative for Renewable Energy in Germany (AIREG): a vast partnership of German private and public stakeholders bringing together different types of expertise in order to share information and increase knowledge on sustainable aviation and biojet (van der Heuvel, 2011).

Source: own elaboration.

It can be asserted that all these supranational research groups and initiatives improve the knowledge on the field and have a positive effect on research in Sweden. In accordance with the boundaries set for this thesis, the contribution to R&D results coming from international actors is acknowledged, but a further analysis of such research activities will not be performed.

Public bodies

According to the Triple Helix model, in addition to industry and the academia, a prominent role in the constellation of actors involved in R&D process is played by public authorities. This assertion holds true in the case of biofuel research. As mentioned before, several governmental agencies encourage research activities by providing funds through a series of programmes and/or by facilitating communication and knowledge sharing among the actors. This group includes: STEM; the Swedish Transport Agency; the Swedish Governmental Agency for Innovation Systems (Vinnova); the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (Formas); the Swedish Research Council (*Vetenskapsrådet*). Although these agencies usually do not have own research activities, it is clear that their contribution to the overall R&D performance is paramount. An examination of the financing initiatives provided is included in paragraph 3.4.1.

Concluding remarks

It is observed that the Swedish strong background in bioenergy research generates both incentives and obstacles to the biojet innovation process. On the one hand, plenty of research on biomass creates a favourable environment and allows Sweden to be a top-notch hub for bioenergy development. This is reflected in the continuous creation of start-ups and other innovative businesses founding their strategy on cutting-edge research and new discoveries. In addition, biofuel research gives indirect benefits to biojet diffusion since a discovery in the former field has often an impact on the latter. On the other hand, however, conventional biofuels draw much of the research attention and funding, which are steered by strong stakeholders with established businesses. A general lack of interest towards biojet among large bioenergy groups is observed. The fact that aviation stakeholders are involved in R&D activities that operate predominantly at the international level contributes to this phenomenon. Even though the attention towards possible developments of biojet is currently low, promising signals of growth in interest can be detected in the increasing collaboration activities among research bodies and supply chain stakeholders. Universities and public authorities give a significant contribution to research with the provision of expertise and funding respectively. These supporting groups of actors need to be steered towards the biojet research area by supply chain stakeholders in order to foster future development.

3.2 Demand-side activities

In order to make the transition to sustainable aviation biofuel possible, in parallel with an expansion of the production capacity from biofuel producers and suppliers it is necessary to create a new market in which actors are willing to buy and use the innovative product. This is, however, a problematic task, because several factors hinder the innovation process, such as actors' resistance to change, difficulty to penetrate a well-established market, initial struggle to operate in a cost-competitive fashion, etc. To overcome these hurdles, demand-side activities encouraging the deployment of innovation need to be performed.

3.2.1 New product markets

Targets setting

The formation of a new product market, or the penetration of an existing market with an innovative product, can be supported by a range of activities from different stakeholders. A first group of actions that influence this development relates to the definition of national, international and sectoral targets.

With regard to biofuel diffusion and deployment of renewable-sourced energy, several binding targets and goals have been set at the national level. Many of these targets are country-specific applications of European legislation, which is acting to steer member states towards a more sustainable economy. The European strategy is in tune with the Swedish government's long-term vision of a low-carbon society. Sweden takes commitment one step further, as can be noted from the fact that national regulation has often set targets that go beyond European targets (McCormick, Bomb, & Deurwaarder, 2012).

The *Renewable Energy Directive* (2009/28/EC), requiring to have 20% of energy consumed in Europe coming from renewable sources by 2020, plays a central role in the act of setting national targets (EC, 2009b). According to the Directive, each country is obliged to fulfil its commitments and to draw an Action Plan illustrating the road map for reaching the targets. In this context, Sweden has pledged to achieve a renewable energy share of 49% of consumption by 2020 (EC, 2009b). In addition, sector-specific targets have been defined in this Directive: the transport sector is required to achieve the target of 10% of total fuel use coming from renewable fuels (EC, 2009b). However, in the Directive it is specified that the aviation sector is not included in the calculation "[due to] the current technological and regulatory constrains that prevent the commercial use of biofuels in aviation" (EC, 2009b, p. 19). This exclusion has severely limited the incentives to a switch to biofuel use in the aviation sector. Likewise, the Government Bill 2008/09:163, *A Cohesive Swedish Climate and Energy Policy – Energy,* defining national targets in light of the Directive and raising the 2020 energy target to 50%, has left out air transportation from the 10% transport target (Swedish Government, 2013). It is interesting to point out that renewable fuel use in the Swedish transport sector has already reached a 15% share, largely beyond the national target (Svebio, pers. comm., 2014). While this is certainly a positive aspect, it has to be observed that a lack of targets to achieve disincentivises further deployment.

A parallel Government Bill, *A Cohesive Swedish Climate and Energy Policy – Climate* (2008/09:162), has structured the country's overarching strategy concerning sustainability issues. A vision of resource-efficient energy supply system with no net emission of GHGs by 2050 has been defined, together with the delineation of a "long-term priority" of establishing a fossil free vehicle fleet by 2030 (Swedish Government, 2013). These priorities have not been further defined and, more than setting practical objectives, simply give general indications to future policymaking activities (Svebio, pers. comm., 2014). Another target set by the Swedish authority is to reduce the national emissions from the sectors not included in the European Union Emission Trading Scheme (EU-ETS) by 40% by 2020 compared to 1990 levels, of which a maximum of one third can be dealt through operations in other EU countries or through the use of the Clean Development Mechanism (CDM) (McCormick et al., 2012; Swedish Government, 2013).

Even though Sweden has a national energy plan that sets targets for energy consumption and supply, including the transportation sector, there are no goals in relation to aviation emissions. The reason for the fact that no targets for the aviation sector have been put in place by STEM is that there is no specific goal for aviation in the Swedish legislation or in any EU directive (STEM-a, pers. comm., 2014). It can be observed that the national legislation gives priority to conventional biofuel deployment and has limited interest in aviation biofuels (TS, pers. comm., 2014).

Another group of targets is identified in EU official documents with relation to air traffic and sustainability. A first document relating to this is a position paper issued by the European Advanced Biofuel FlightPath initiative (see section 3.1.1), whose vision entails the achievement of 2 million tons of sustainable biofuels use in aviation by 2020 (Biofuels Flightpath Initiative, 2013); a roadmap for achieving the target, and to proceed towards a 2050 sustainable aviation, has been designed. The European Commission also adopted the White

Paper, a document drafting the roadmap to a sustainable European transportation system and setting a 40% target of use of sustainable low carbon fuels in aviation by 2050 (EC, 2011b). In addition, *Flightpath 2050 Europe*, a document from the European Commission identifying the long-term strategy of European aviation (see section 3.1.1), set the target of 75% reduction in CO_2 emissions and 90% NO_X emissions, using typical new aircrafts performance in year 2000 as a baseline for comparison (EC, 2011a). Given that these targets are not coming from regulatory acts but from documents envisioning future development strategies, they are to be considered as aspirational goals rather than mandatory measures, and therefore their contribution to increase biofuel demand is limited. On the other hand, these goals contribute to raise awareness about the issue of aviation sustainability, and indicate the way for future development.

In addition, the aviation industry has established self-imposed measures that can spur the utilisation of biofuels in aviation. In 2009, the International Air Transport Association (IATA), representing ca. 84% of global air traffic, has committed to improve fuel efficiency by 1,5% per year on average until 2020, to reach carbon-neutral growth in 2020, and to halve net CO_2 emissions by 2050 compared to 2005 levels (IATA, 2009). In 2010, the International Civil Aviation Organisation (ICAO) has improved part of these commitments, defining a target of 2% annual fuel efficiency improvement until 2020 and an aspirational goal of 2% yearly improved efficiency until 2050 that goes beyond a carbon-neutral growth of the sector (ICAO, 2010). Moreover, ICAO member states have to report their research activities, and to submit a national plan to reduce their national CO_2 emissions (TS, pers. comm., 2014). On an overall level, the aviation sector has put in place several environmental targets regarding fuel efficiency and emissions reduction, but these measures are not setting targets for biojet.

At the national level, the Swedish airline industry has not set targets on top of the international commitments, and the initiative to pledge to self-imposed targets is left to individual firms. The number of Swedish airlines setting further commitments is very small.

Market-based measures

A group of activities that contribute to the creation and development of a new market involve the use of market-based measures as an instrument to increase the demand of the innovative product. Measures contributing to the deployment of the biofuel and biojet market include instruments providing financial support in the form of direct or indirect subsidies, quota obligation systems, and emission trading schemes.

Allocation of subsidies and tax exemptions can lower the cost of producing an innovative product and therefore facilitate the diffusion of innovation competing with traditional products (Wiesenthal et al., 2009). Financial support can be progressively removed as the experience level proceeds through the learning curve and the production costs of the innovative product decrease. For example, the European *Energy Taxation Directive* (2003/96/EC) – and in the Swedish legislation *Act* (2010:598) *concerning sustainable criteria for biofuels for transport and liquid biofuels* – exempt biofuels from numerous tax obligations, making them more competitive in the market. Such regulations entail the use of financial mechanisms, and therefore will be further described in section 3.4.1.

An opposite measure to subsidisation is the use of mandatory measures for production and use of biojet. In the case of biofuel produced for conventional applications such as road transport, this kind of measure consists of the prescription of a compulsory fixed amount of biofuel to be supplied by fuel providers, as a share as their total sales (Wiesenthal et al., 2009). Mandatory blending requirements encourage the diffusion of biofuels as they guarantee the existence of a minimum share of the market for the product (Charles & Wooders, 2011).

Imposing the quota system to suppliers rather than users is due to the fact that is difficult to apply the mandatory measure to private fuel users, and that this design simplifies the administrative aspects of the system; but ultimately, final transport users are the ones who bear the costs of the quota (Wiesenthal et al., 2009). In the aviation sector, a quota obligation system would be structured in a similar manner, with oil companies being responsible for ensuring the required share of biofuel into the blended fuel. An obligation system put on airline companies or fuel importers entails many issues, because the former purchase the fuel directly from the airport pump and the latter would have logistic importing problems (Norberg, 2014). In practice, the obligation system would consist of imposing a certain share of the jet fuel sold on the market to be consisting of renewable biofuel. Blending of conventional jet fuel and biojet is made possible by the fact that ASTM-certified biojet has the identical performance of any Jet A-1 fuel.

The Swedish Energy Agency and the Swedish Transport Agency are considering the possibility of introducing a renewable fuel quota obligation system in the Swedish jet fuel market. A recent Master Thesis at Lund University assessed the prospects of introducing a quota obligation for aviation, starting with a 2% mandate progressively increasing to 40% by 2040 (Norberg, 2014). The study concludes that implementation of a quota obligation system is in accordance with ICAO regulation, and would lead to a growth in ticket prices. Even though increased prices are not likely to have a negative impact on the demand, Swedish airlines would become less competitive (Norberg, 2014). This is the reason why a quota obligation system is not well perceived by some airline companies, which would prefer alternative solutions. This aspect is further discussed in section 3.3.1.

The use of the European Emission Trading Scheme as a market-based instrument to reduce carbon emissions merits a separate discussion. The EU-ETS, operating in the 28 EU member states and the three EEA-EFTA countries[3], sets a cap on the total GHG emissions coming from energy-intensive industrial sectors, accounting for roughly 45% of the total EU GHG emissions (EC, 2014b). The total amount of emissions is divided into a limited number of allowances, which are distributed among the companies operating in the system. Since at the end of each year every company needs to own allowances to cover all its emissions, companies that manage to reduce their emissions can sell their allowances to companies that do not cut their emissions. Therefore, the trading of allowances ensures that the overall level of emissions is reduced and that the reduction is performed in the most efficient way (EC, 2014b).

In the Directive 2008/101/EC, known as the Aviation Directive, EU member states agreed to include the European aviation sector – including all flights within, into and out of the EU – in the European Emission Trading Scheme, starting from 2012 with a 97% cap on emissions compared to 2004-2006 emission levels and progressively reducing the cap in the upcoming years (OECD, 2012; van der Heuvel, 2011). Adoption of this targets would have required airline companies to reduce air traffic emissions through the use of biofuels, which is the only solution that provides such significant effects in the short- and mid-term (van der Heuvel, 2011). This is the reason why the inclusion of aviation in the trading scheme met strong opposition by many countries outside of the EU and several airline associations, bringing along political and legal actions against it (Bartels, 2012; OECD, 2012). To avoid international disputes, the EU decided to suspend the inclusion of flights from and to countries not belonging to the EU in the scheme until 2016 (EC, 2014b).

[3] EEA-EFTA countries included in the scheme are Iceland, Lietchenstein and Norway.

A 2010 study by Anger and Köhler argues that inclusion of aviation in the trading scheme would have produced negligible results (Anger & Köhler, 2010). Due to the low-cost credits available in the market, the aviation sector would have simply bought allowances from other sectors participating the EU-ETS. Moreover, the cost of purchased allowances would have been passed on to customers, whose demand is argued to be rather inelastic (Anger & Köhler, 2010). The study concludes that, even though the EU-ETS would have not put pressure on the aviation sector for a switch to sustainable fuels, the proposal of including aviation in the Emission Trading Scheme had the merit to draw attention towards sustainability issues in the sector (Anger & Köhler, 2010). However, the study does not consider the possible outcomes of the inclusion of aviation emissions in a revised and more effective form of the EU-ETS.

Since the aviation industry had been procrastinating the foundation of a global system for reducing aviation emissions, the EU decided to create their own system. The rationale behind this inclusion was therefore to accelerate the formation of an international framework for emission reduction of air travel. Given this consideration, the EU effort achieved a significant result when in October 2013 the UN agency ICAO agreed to establish an international sector-specific market-based measure for emissions reduction in aviation. The measure should be developed by 2016 and will be implemented by 2020 (EC, 2014b). It should also be highlighted that, according to several authors, so far the EU ETS has had questionable performances, partially because of the over-allocation of allowances causing a drop in allowance prices (Ellerman & Buchner, 2008; Ellerman, Marcantonini, & Zaklan, 2014; Jong, Couwenberg, & Woerdman, 2013). Though the EU is carrying out adjustments to improve the efficiency of its trading system, having a separate measure for aviation emissions, possibly an emission trading scheme, could prove to be more effective than the current EU-ETS to foster production and use of biojet.

All in all, the inclusion of aviation in a specifically designed market-based instrument could be a strong driver for increasing the environmental performance of air travel. However, this system has not been defined yet, and is therefore not possible to assess the extent to which it will be effective in promoting the use of alternative fuels.

Advocacy and legitimation

The transition to renewable fuels in aviation is, at the moment, not considered a priority by the Swedish authorities (TS, pers. comm., 2014). This is reflected in a scant involvement of the government and the Ministry of Enterprise into the setting of targets for the deployment of biojets. Much more attention is given to conventional uses of biofuel, partly because of the presence of a strong network of enterprises involved in the bioresources market (Svebio, pers. comm., 2014). Moreover, looking at the situation in a wider perspective, it has to be pointed out that the importance of the contribution of biofuels to the creation of a sustainable energy system has been recently questioned within the EU (Svebio, pers. comm., 2014; Ulmanen, Verbong, & Raven, 2009). Therefore, biojet stakeholders have the critical task to steer the public authority's attention towards this issue through legitimation and advocacy activities, highlighting the benefits and the suitability of biojet use.

Swedish biofuel development has been influenced by several lobbying groups – the methanol advocates led by Volvo in the 1970s, the ethanol group in the 1980s, the biogas supporters later on, eventually merging in a unified biofuel advocacy coalition (Ulmanen et al., 2009). This shows that successful advocacy activities are performed by a united constellation of different actors. The aviation industry has to play a major role in this setting, demonstrating the importance of renewable jet fuels for a more sustainable air transportation system. The Nordic Initiative for Sustainable Aviation (NISA), an association involving numerous Scandinavian stakeholders, is conducting a dialogue with policy makers concerning the means of moving the transition forward. A crucial factor for success is the extent to which the biojet interest associations will be able to actively engage the Swedish bioenergy group for promoting sustainable jet fuels at the national level. One obstacle to collaboration with bioenergy stakeholders is the concern that there will not be enough biomass to cover the aggregate demand of aviation, road transport and heating, and that this will lead to a competition for resources among sectors.

Diffusion of information gives a significant help to legitimation. Communicating to policymakers that biofuels are the only valid short-term alternative for reducing air travel emissions is a first step for pointing out the importance of biofuel deployment for the aviation industry. In addition, biofuels environmental performance should be promoted, clarifying the difference between first- and second-generation biofuels and supporting the diffusion of the latter rather than the former. With this regard, support to the legitimation process can be provided by external NGOs. Internationally recognised environmental organisations, for example, have a great influence on ensuring the sustainability of feedstock and fuels, because their approval to a product can be more effective than a certification scheme. These issues will be further discussed in section 3.3.1.

In order to conduct an effective lobbying, supply chain actors, and particularly airline companies, should design their environmental strategy thoughtfully. Stakeholders with a traditional business approach consider sustainability issues a nuisance and, as environmental laggards, would lobby against the diffusion of alternative fuels. This does not seem to be the case for the aviation industry, which on an overall scale appears to be welcoming sustainable innovation in fuels. However, differences in the degree to which airlines would like to participate in the transition process can be observed. As a result, there are a variety of opinions about the measures that the government should take. Current lobbying efforts have contrasting results because every actor advocates for its own propositions instead of having a common goal with other stakeholders. To solve this issue, actors should converge their views towards a shared agenda, and use large association groups to push these requests forward.

Concluding remarks

From the analysis of activities aiming to facilitate the creation of a market demand for biojet, it appears that the process of creating new product markets needs further support. Though numerous targets with relation to biofuel development have been set by national and European regulations, they provide few incentives for the diffusion of biojet, either because the targets have been already reached or because they do not address air transportation specifically. At the national level, the vision of a sustainable aviation advanced in official documents has not been translated into binding targets, but has remained an aspirational goal. The same reasoning can be applied to European documents on sustainable aviation, whose aims and targets do not have a strong impact on the creation of a demand for biojet. The many environmental targets set by the international aviation industry show a concern over aviation sustainability, but, once again, they are non-binding targets. No market-based measures are currently implemented, and establishing a national framework to spur biojet use appears to be troublesome. On the other hand, the announcement of an ICAO market-based measure implementation starting from 2020 is a promising signal for the future. Advocacy activities can play a relevant role to spur the formation of a new market from the demand side, but it is first necessary to define a shared strategy among the interested actors.

3.2.2 Quality requirements

This section presents the activities related to the implementation and change of biofuel quality standards. As argued by Wiesenthal et al. (2009), the existence of biofuel standards is paramount for the market development of biofuels, since it ensures the quality of the products and facilitates the international trade operations.

As introduced in Section 1.1.3, in order to be eligible for use in air transportation, biojet must abide by specific requirements. The fuel used needs to have the same quality and characteristics of conventional Jet A-1 fuels, so that it can conform to the existing aircraft design (ATAG, 2009). ASTM International, the global leader in voluntary standards development, has set two jet fuel specifications, ASTM D1655 – *Standard Specification for Aviation Turbine Fuel*, and ASTM D7566 – *Aviation Turbine Fuel Containing Synthetized Hydrocarbons* (ATAG, 2011). The latter specifies the quality requirements for jet fuel derived from biomass. If the specification requirements are met, a Certificate of Quality is issued, proving the conformity to the ASTM D7566 standard (SkyNRG, n.d.-a). At this point, biomass-derived fuel can be blended with conventional fuel; a drop-in of up to 50% of renewable fuel is allowed (ATAG, 2011). The blended fuel is inspected again, and upon certification with the ASTM D1655 standard it can be used in all existing infrastructure (SkyNRG, n.d.-a).

F-T used to be the only production process to be permitted in the original regulation, but the certification design enables to include various types of alternative fuel once it is proved that they comply to the necessary requirements (ATAG, 2011). Thanks to this feature, a revision of the specification was introduced in 2011, defining the requirements for synthetic fuel components obtained with the HEFA process (ASTM, 2011). A recent revision in 2014 allowed the use of a third type of fuel, Synthetised Iso-Paraffinic (SIP) fuel, obtained through the DSHC process (ASTM, 2014; Rumizen, 2014). Inclusion of other new technologies is to be expected in the near future, as some of the alternative processes described in section 1.1.3 are currently undergoing the ASTM certification procedure (Statoil Aviation, pers. comm., 2014). Since Jet A-1 is the type of fuel globally used in modern aviation, with the exception of the United States in which Jet A fuel is used (Shell, n.d.), the ASTM certification guarantees a global standard for aviation conventional fuel and biofuel.

A noteworthy discussion related to quality requirements is with regard to standards and methods for feedstock categorisation. Categorisation methods and connected regulation are of interest to biojet producers and suppliers, because they strongly influence the choice of technology and feedstock to invest in. Feedstocks (and biofuels) are typically classified as first-generation (conventional) or second-generation (advanced), the former primarly consisting of food crops such as sugar beets, grains and oil seeds, the latter of non-food biomass like energy crops and lignocellulosic material (Sims, Taylor, & Saddler, 2008). As introduced in section 1.1.3, the classification highlights the different environmental performances these two groups have in a life-cycle perspective. Unlike products belonging to the former group, second-generation feedstocks do not compete directly with food crops (EC, 2012). Conversely, when feedstock is grown on existing agricultural land, the substitution of food production with feedstock production for biofuels implies a diminished production of food, which might result in producing food somewhere else by changing land not originally used for agriculture; this concept is known as indirect land-use change (see section 1.1.3) (EC, 2012). For this reason, substituting conventional fuels with first-generation biofuels reduces the environmental impact only to a limited extent. In order to make a significant contribution to GHG emissions reduction, biofuels should be produced from sustainable second-generation feedstock.

The European legislation does not provide a precise distinction between first- and second-generation biofuels (Svebio, pers. comm., 2014). The current regulation is set by the Renewables Directive (2009/28/EC), which sets biofuels sustainability criteria and GHG emission calculation methods. Biofuels are considered sustainable if they emit at least 35% less GHG emissions than petrol; this amount will rise to 50% in 2017, and to 60% for products coming from installations built from 2018 onwards (EC, 2009b). The European law has also set a cap of 5% as the limit to which food-derived feedstock can contribute to the 10% renewable energy target for transportation, strengthening the incentives for an expansion of second-generation biofuels (EC, 2012). A new regulatory framework for promotion of biofuels in the EU has been proposed, with the aim to raise the sustainability criterion of saved GHG emissions to 60% (MSL Group, 2012). However, the implementation of the new regulation has been postponed due to pressure from conventional biofuel stakeholders (Nichols, 2013).

Despite the terms "first generation" and "second generation" are widely used in the literature, the fact that no detailed categorisation method has been defined by the European legislation creates uncertainty for investors, who are unable to invest financial capital on specific feedstocks and technologies (Svebio, pers. comm., 2014). An ambiguous categorisation system increases the difficulty of foreseeing the future regulation setting, and consequently to identify the feedstocks that are going to be considered sustainable in the long term (Svebio, pers. comm., 2014). This problem is worsened by the lack of clarity in defining the ILUC phenomenon and other sustainability criteria, creating uncertainty in the market and making the setting of targets problematic (Bacovsky, 2011; Voegele, 2014). The need of addressing the ILUC issue has been also pointed out by industry representatives like SAFUG (SAFUG, 2013). To alleviate this problem, the EU Energy Council has recently reached an agreement that addresses the ILUC issue and its definition, encouraging a transition to more sustainable fuels. The agreement places a 7% cap on conventional fuel use for the 10% transportation target, and sets a sub-target of 0.5% to be covered by advanced biofuels (EU Council, 2014; Voegele, 2014). However, the agreement still has to negotiatied in the newly formed EU parliament and needs to be signed off by energy ministers to be implemented (Muzi, 2014).

Concerning the area of self-imposed quality standards, ICAO has compiled a list of voluntary measures taken by several stakeholders in order to reduce the impact of aviation on climate change (ICAO, 2010). The group comprises many different operations including aircraft renewal, aerodynamics improvement, fuel efficient flight planning, reduction of weight, carbon offsetting measures and so on (ICAO, 2010). International ICAO standards, even being voluntary, have a positive impact on aviation emissions reduction, because manufacturers and producers are induced to conform to the standards (TS, pers. comm., 2014). However, given that biojet fuels have the same characteristics of conventional jet fuels, these standards do not contribute to their market expansion, but simply optimise air travel environmental performance.

Concluding remarks

The existence of internationally recognised standards for Jet A-1 biofuels provides a solid basis for the innovation process. Three production processes have already been certified, and others will soon be included. This will broaden process and feedstock availability for biojet production, encouraging alternative means of production and creating a diversified supply. In contrast, a lack of clarity with regard to the issue of process and feedstock sustainability has been observed. The legislative framework is proceeding in the right direction to define sustainability criteria for first and second generation biofuel classification, but the progress goes at a slow pace since many interests are involved.

3.3 System constituents

3.3.1 Organisations

This section discusses system organisations, that is, the actors that influence the innovation process. To ease the understanding of organisations in the system, the actors have been divided into groups, according to their characteristics and functions within the SI. Thereby, the discourse will proceed by describing each actor category, their main features and core activities, including some exemplifying actors that play a relevant role in the SI. In addition, the actors' interests and benefits from the development of a biojet market are discussed.

It may be noted that this section contains a larger amount of data than the other sections. This is due to the fact that organisations and their activities constitute the backbone of the innovation system, whose examination implies a thorough analysis of such actors.

Companies

Companies are the organisations that are involved in the biojet supply chain. The group comprises all the firms that take part in the production, distribution and use of biofuels. As the market dynamics generate very different roles within the group, these three stages divide the actors into subcategories: producers and suppliers; distributors; users.

Producers and suppliers

The first subgroup is composed of the firms involved in producing and supplying activities, such as oil companies, refineries, feedstock and biofuel producers, importers. Their operations include all the activities related to the production of jet fuel, from feedstock production to its processing and refining. Suppliers are the actors responsible of blending biofuel with conventional fuel, to deliver the final product to the airport, and at times to sell it to airline companies. Therefore, a potential quota obligation system would impose on these actors a mandate to drop-in a certain amount of biofuel into their product.

At the beginning of the supply chain are found businesses producing or importing feedstock, converting it into jet fuel and selling it to oil companies. These actors are often involved in high-level research activities, which are paramount for developing their innovative products and gain competitive advantage. Therefore, research on feedstock, new technologies and sustainability is supported by them. Diffusion of biojet fuels would entail great economic benefits for biofuel producers, which are currently acting in a niche market with a limited demand for sustainable fuel.

A major actor is Neste Oil, a Finland-based international fuel company, operating in the sectors of oil products, renewable fuels and oil retail (Neste Oil, n.d.-a); the country of Finland holds controlling interest in the company. Currently, renewable diesel is Neste Oil's main product, although the demand of renewable jet fuel is expected to grow in the coming years (Neste Oil, pers. comm., 2014). In 2013, jet fuel sales constituted 4% of the total revenues, which accounted for circa 17.5 million EUR (Neste Oil, 2013). Production of renewable fuels is carried out through the NEXBTL technology, a self-developed process that embodies a high level of technical complexity and know-how. This is an indicator of the company's highly involvement in R&D activities, which also include intensive research on renewable inputs (Neste Oil, n.d.-b). The NEXBTL process allows the production and refining of renewable jet fuel, which is primarily sold to oil companies in Europe and North America (Neste Oil, 2013). Several types of feedstock can be used for the process, ranging from waste and residue-based materials to vegetable oils; feedstock sourcing is operating at the global level. Neste Oil's future strategy in relation to renewable fuels consists of securing not only a flexible feedstock base but also the sustainability of its products (Neste Oil, 2013).

A significant share of Sweden's industry uses forest-based biomass for its core activities. This is, for instance, the case of the well-established pulp and paper sector. The sector, characterised by a high level of competitive pressure and development, contains potential stakeholders for the biojet market. A small group of companies, such as those belonging to the Paper Province cluster, are already investigating the possibility of growing feedstock for biojet production. The Paper Province cluster comprises a series of business actors aiming to develop a forest-based bioeconomy in the county of Värmland; their involvement in the biojet innovation process can be noted by the fact that the cluster is one of the key partners in the Karlstad Airport Bioport project (presented in section 3.3.1) (SkyNRG, 2014). A number of barriers to grow feedstock for biojet exist: these include the current unprofitability of producing such feedstock compared to conventional products, and the lack of clarity in the definition of sustainable feedstock. However, companies believe that large business opportunities may become available once these issues are overcome (Paper Province, pers. comm., 2014). The Paper Province cluster is being financially sponsored by Vinnova in order to broaden its activities and mobilise more organisations and enterprises to take part in discovering new cross-sector services and products from the traditional pulp and paper industry (Vinnova, pers. comm., 2014).

Oil companies are the actors in the supply chain with the task of sourcing jet fuel and delivering it to the airport. They also have the responsibility to blend biojet with conventional jet fuel in accordance to standards and regulation. At the current stage the demand for biojet is scarce, so that oil companies deal with a limited quantity of biojet. Companies with expertise in renewable fuel would benefit from an increase in the biojet demand by gaining competitive advantage.

Statoil Fuel & Retail Aviation AS, or simply Statoil Aviation, is one of the major jet fuel suppliers in the Nordic countries, operating in more than 75 airports in the region, twelve of which are located in Sweden (Statoil Aviation, pers. comm., 2014). The company is responsible of handling, transporting and storing jet fuel, covering several steps of the supply chain (Statoil Aviation, n.d.). In order to obtain raw materials, the company works in cooperation with producers and retailers like Neste Oil and SkyNRG.

Biofuels are seen by Statoil Aviation as an opportunity to take a leading role in the region, both in the short and the long term (Statoil Aviation, pers. comm., 2014). To achieve this goal, a long-standing plan has been developed. According to this strategy, short-term activities being carried out in the short term consist of the promotion of biofuels through demonstration flights and pilot projects (Statoil Aviation, pers. comm., 2014). However, in order to foster the diffusion of biofuels, a more significant capacity needs to be reached in the mid-term. Hence, the company's mid-term objective is to substantially increase the volume of biofuel operations by 2015 (Statoil Aviation, pers. comm., 2014). The company believes that the existing price gap needs to be bridged through subsidies and companies' corporate programs to offset carbon emissions via their flights (Statoil Aviation, pers. comm., 2014). In the long-term, Statoil Aviation aims to establish biofuel local production in the Nordic region; this goal is backed by the numerous initiatives in Norway and Denmark, in which biofuel production is being developed in a long-term perspective (Statoil Aviation, pers. comm., 2014). In Sweden there is a smaller amount of such activities, although the companies has observed promising signals of future development (Statoil Aviation, pers. comm., 2014). The rationale of having a general focus on the Nordic region, for local production, rather than on a specific country, is to be found in the flexibility of targeting various countries and identifying the most efficient logistics and political support available (Statoil Aviation, pers. comm., 2014). According to the company's opinion, Sweden has great potential for development of local production, due to the possibility of achieving synergies with existing infrastructure and logistics (Statoil Aviation, pers. comm., 2014). Nevertheless, countries like Norway and Finland currently have a more favourable setting for development, because of financial availability and political will for the former and presence of companies with expertise in the field for the latter (Statoil Aviation, pers. comm., 2014).

Apart from supplying activities, Statoil Aviation plays a role in R&D operations by contributing with infrastructure, competence and logistic support (Statoil Aviation, pers. comm., 2014). The company participates in projects fostering local production development, such as the Karlstad Bioport project discussed in the Distributors section.

In the producers group are also included companies which, rather than dealing with biojets as a branch of their activities, are specifically devoted to the production and sale of renewable aviation fuels. These firms' success is strictly dependent on the future development of a biojet market. Therefore, apart from production and sale operations, the companies are highly committed in performing actions supporting biojet development, such as research, advocacy and networking, and they are partners in several projects and initiatives in various areas of the SI.

A leading company with these features is the Dutch-based SkyNRG. The company, founded by Air France-KLM Group, North Sea Group and Spring Associates, develops and sells sustainable jet fuel at the global scale (SkyNRG, n.d.-b). The long-term vision of the company comprises the establishment of regional bioports: this term is used to indicate an integrated regional supply chain for biojet fuel production, extending from local production of feedstock to biojet usage by end-users. SkyNRG, partnered with leading NGOs to ensure the sustainability of the fuel, has a strict scope on sustainable feedstock and conversion processes (SkyNRG, pers. comm., 2014). The current core activities consist of purchase of renewable diesel, distillation to remove the heavy diesel fraction, and sale of the final product – biojet (SkyNRG, pers. comm., 2014).

Creating a bioport requires the creation of a solid supply chain and therefore is important to establish contacts with actors alongside the production process. Issues at any stage of the process, such as the scarcity of renewable fuel suppliers in the market and the current high cost of feedstock, have to be identified and addressed. The difficulty of finding sustainable feedstock in the market makes it necessary for SkyNRG to have a proactive role on their feedstock sourcing activities by assisting farmers to develop a sustainable feedstock production (SkyNRG, pers. comm., 2014). Other complementary activities include the participation in research projects, demonstration flights and advocacy.

Some of the largest oil companies in the market are not currently operating with biojet products, but they might enter the market in the future. This is the case for Preem Petroleum AB, Sweden's largest oil company, controlling two thirds of the national refining capacity (Ekbom, Hjerpe, Hagström, & Hermann, 2009). Many actors point out that synergies could be achieved by using existing refining infrastructure and expertise for biojet production.

All in all, it can be noted that even within the producers subgroup there are different actors and interests. Due to the supply chain inherent characteristics, an array of actors operating at multiple stages can be found. Categorisation into groups helps to describe supply chain dynamics, but it should be pointed out that these groups are flexible.

Distributors

Members of this subgroup are the companies that facilitate the contact between producers and users and establish the logistic infrastructure for distributing the product. In the Swedish jet fuel supply chain this role is performed by airports, which are the entities that act as middlemen between fuel companies and airlines. Different logistic systems varying from airport to airport exist, although usually fuel companies use the infrastructure provided by the airport for selling their fuel to airlines. Therefore, airports do not participate directly in fuel sale activities, but are often responsible for handling aircraft refuelling operations.

The largest actor in distributing operations is Swedavia, a state-held company owning and managing ten airports in Sweden. The government used to control a larger number of airports in the past through the Swedish Civil Aviation Administration (in Swedish: *Luftfartsverket*, or LFV), but in 2009 the parliament decided to give part of aviation responsibilities to a new company, Swedavia (Swedavia, pers. comm., 2014). Formed in 2010, Swedavia controls commercial airport operations, while LFV keeps administering air navigation services. This decision entailed the reduction of the number of controlled airports to ten, leaving the management of smaller airports to privates or municipalities (Swedavia, pers. comm., 2014). Therefore, it is Swedavia's task to administer the principal Swedish airports, handling the vast majority of air travel in the country.

As a distributor, Swedavia does not participate in the sale of fuel to airlines; this task is performed by fuel companies. Although the specific logistic systems change from airport to airport, it can be summarised that fuel companies utilise airport infrastructure for their fuel sale operations. Detailed information regarding the market share of fuel suppliers and customers has not been shared (Swedavia, pers. comm., 2014).

Being a public-owned company, the group considers environmental matters an important issue to address. This is shown in the strong environmental management practices performed regarding airport operations. Having achieved the highest grade in the Airport Carbon Accreditation (ACA) standard in 2006, Swedavia claims to have carbon-neutral operations for all the activities over which it has control (ACI Europe, 2009; Swedavia, pers. comm., 2014). Carbon neutrality is achieved by reducing the carbon footprint of airport operations, and by investing in climate compensation projects worldwide through a CDM instrument (Swedavia, pers. comm., 2014). With regard to biojet development and diffusion, the group participates in a few initiatives related to R&D and demonstration projects. For instance, in 2009 LFV co-financed a feasibility study assessing the possibilities of starting a commercial biojet production in a biorefinery near Stockholm Arlanda Airport. The pre-study showed that large production volumes could make biojet price comparable to conventional fuel price (Ekbom et al., 2009). As a result of the study, Swedavia signed a letter of intent with the biojet company Solena with the goal to get a full-scale production of biojet to be used at Stockholm Arlanda Airport (Swedavia, pers. comm., 2014). The intention of Swedavia is to act as an intermediary between Solena and local actors (Swedavia, pers. comm., 2014).

Swedavia identifies the high spread between conventional fuel and renewable fuel prices as a key obstacle for biojet diffusion (Swedavia, pers. comm., 2014). Other identified barriers are the lack of availability of aviation fuel and the risk of competition for bioresources with road transport and energy production (Swedavia, pers. comm., 2014). Moreover, it seems that the large size of many Swedavia airports could be an additional barrier for the establishment of a local production system. As the overall sustainability of aviation is critical for Swedavia's future, the company identifies its own role as a catalyst of biojet diffusion (Swedavia, pers. comm., 2014).

Swedavia administers the largest Swedish airports, but there are a number of smaller airports operating independently. One of these, Karlstad Airport, is a forerunner in the use of biojet fuel. The airport is owned and administered by the Municipality of Karlstad, which has set a high environmental commitment in the airport operations (Karlstad Airport, pers. comm., 2014). In the autumn of 2013, a dialogue between Statoil and Karlstad Airport began, and the two organisations carried out an investigation to identify means to reduce the environmental impact of aviation (Karlstad Airport, pers. comm., 2014). The outcome of this process revealed the opportunity of providing biojet fuel at Karlstad Airport; this initiative has been named *Karlstad Bioport project*. For the sake of clarification it should be pointed out that the project is very recent and is currently undergoing its starting phase. With the collaboration of SkyNRG, a storage tank for biojet fuel has been built, starting its operations in June 2014. The tank contains 100% biojet fuel, which is blended with conventional fuel thanks to designed mixing machinery. The percentage of blended biojet can vary on demand. The facility entails the use of special tank cars for transporting biojet fuel to and from the storage tank. Currently, biojet is imported by SkyNRG from international producers.

According to Karlstad Airport, this type of facility is the first full-scale plant in Europe (and possibly the world) in terms of biojet blending technology and logistics. The facility aims to demonstrate the efficiency, reliability, feasibility and safety or the blending fuel system. In the long run the Bioport project aims to become a role model for other airports. According an Airport spokesperson, some companies in the Nordic region are already landing their aircrafts at Karlstad Airport in order to fuel them with biojet for demonstration flights (Karlstad Airport, pers. comm., 2014).

At the current stage, airline companies can decide to buy biojet fuel in different blending percentages, typically ranging from 10% to 45% according to the customer's choice (Karlstad Airport, pers. comm., 2014). Buying biojet blend entails the payment of a premium price, due to the fact that currently biojet has a cost that is higher than conventional fuel by a factor of three or four (Karlstad Airport, pers. comm., 2014). However, Karlstad Airport's objective is to cover the premium cost of buying biojet through the use of a specifically designed fund, the Fly Green Fund (FGF), by the beginning of 2015 (Karlstad Airport, n.d.). Businesses, public bodies and individuals can contribute to the FGF, which would be used to bridge the price gap between conventional fuel and biojet, enabling airline companies to purchase the two at the same price. In this way, all airlines operating at Karlstad Airport would be enabled to use biojet without paying a premium, choosing any blending percentage allowed by the regulation (that is, up to 50%). Since the Fly Green Fund provides financial incentives to renewable fuel use, it will be further examined in section 3.4.1.

The short-term strategy for the Karlstad Bioport project consists of launching the Fly Green Fund and engaging stakeholders to participate in the fund financing process. The company calculates that the FGF will be launched by the end of October 2014 (Karlstad Airport, pers. comm., 2014). The long-term plan is to establish a regional production of biojet through the creation of a supply chain at the local level. This goal necessitates the engagement of the local forestry and energy industries in the project; a cluster of actors involved in biomass production, the Paper Province, has already been involved. The benefit of establishing a local production is given by the reduction of international procurement dependency.

As noted, the main driver inducing Karlstad Airport to diffuse the use of biojet comes from Karlstad Municipality's high commitment to environmental issues. Arguably, Swedavia could be interested in biojets for the same reason, as both organisations are public-owned and operating in the same market. Representatives of Karlstad Airport assert that this assumption is correct on a theoretical level, but a hurdle is represented by the larger scale of Swedavia's operations. To overcome this problem, the Swedavia could start bioports development in smaller airports like Östersund and Visby, and include bigger airports in the process only in a second stage, when expertise and capacity have reached higher levels (Karlstad Airport, pers. comm., 2014).

Users

The users subgroup comprises the firms that lie at the end of the supply chain and utilise the final product for their core operations. The most representative actors are airline companies whose operations include flights from, to or within Sweden. These actors usually purchase jet fuel directly at the airport pump, therefore having no involvement in refining, blending and logistic operations. Some of the largest users, however, are co-owners of the distribution systems in some airports; this is the case, for instance, of Scandinavian Airlines.

There are several drivers for airline companies encouraging the shift to biofuels in air transportation. Airlines involved in the development of a bioport would have strategic and economic benefits. These companies currently have little control of their fuel supply, making them dependent on market fluctuations and bargaining power of suppliers. By participating in bioports development, airlines can establish a control over the fuel supply, increasing the margins for profit (SkyNRG, pers. comm., 2014). Reaching upstream levels of the biojet value chain would allow airlines to improve their power balance and secure the sustainability and availability of future supply (van der Heuvel, 2011).

Additional reasons justify the interest of the aviation industry in biofuels, even for airlines that are not involved in bioport initiatives. Generally speaking, the aviation sector has been pressured to curb its carbon emissions, but this has proved to be more difficult than, for example, in the road transport industry, due to the peculiarity of the air travel business, which entails high technological and administrative complexity (STEM-b, pers. comm., 2014). Some of the air transport industry has therefore realised that it is better to proactively contribute to research, environmental targets, and design of environmental measures, rather than being subjected to legislation in a top-down approach. Some researchers argue that the practical outcome of R&D and demonstration activities is going to be fairly limited, and that these actions are primarily to show that some efforts are being made (A. Karyd, pers. comm., 2014). Although this assertion might hold true to a certain extent, it should be noted that research initiatives have somewhat contributed to increasing the overall knowledge in the field; whether it will lead to a wide diffusion of biojets is difficult to say. Likewise, the industry has pledged to introduce measures (such as the soon-to-be-established ICAO market-based measure) to sustain the transition to biofuels. All in all, it is probably too soon to evaluate the effectiveness of such commitments.

As a general statement, users do not perform biojet-related operations individually, but rather leave this type of activities to associations with specific goals formed by groups of users. Therefore, many of the Swedish and Nordic users have transferred their activities and efforts into NISA, which acts as the main actor representing the users group. The association's operations are described later on in this section. For this reason, only few actors conduct large individual initiatives.

In the Swedish air transportation market a prominent role is played by Scandinavian Airlines, providing air transport services in the region with passenger market shares of 48% for domestic flights and 20% for international flights (SAS Group, 2013). Scandinavian Airlines is controlled by the airline holding company SAS Group, which is partially owned (50%) by the Swedish, Norwegian and Danish governments. Purchase of jet fuel, accounting for 1.3 million tons a year, is one of the company's crucial operations among the core activities. For this reason, the company is having a proactive interest in biojet innovation, and is involved in several initiatives that contribute to the transition process.

At the present time SAS is not using aviation biofuel in its flights, but intends to become a forerunner of biojet use in Sweden. The company believes that setting goals for the use of biofuels in demonstration flights is an outdated strategy, and is aiming at establish a sustained use of biojet on a large scale for its operations (SAS, pers. comm., 2014). In accordance to this vision, self-imposed targets have been set within the company: to establish by 2015 a contract with fuel suppliers to purchase a significant amount of sustainable fuel; to use a certain volume of sustainable fuel in core operations by 2020 (SAS, pers. comm., 2014). The first target has proved to be difficult to reach, and will be probably delayed. Currently, SAS is working with SkyNRG and Statoil to arrange a contract for biojet delivery in 2017 or 2018 (SAS, pers. comm., 2014). Current efforts are focusing on assessing the possibilities of renewable fuel deployment. This entails a dialogue with the public authority with regard to incentives and financing models, because it is believed that policymakers are about to start addressing the issue of sustainability in aviation. On the long run, SAS does not have a particular interest in establishing a local production of biojet, but believes that could be a good business opportunity for the Swedish forestry industry (SAS, pers. comm., 2014).

The company performs strong networking activities to spur biojet research, production and use. This is derived from the understanding that a joint collaboration among different stakeholders is more effective that individual efforts. In this light, SAS has been the initiator of the Nordic Initiative for Sustainable Aviation, which now entails a dialogue with various actors in the aviation industry, fuel producers groups, public agencies and so on (SAS, pers. comm., 2014). National-level research in collaboration with third parties is also promoted; see section 3.1.1 for further information. In addition, a number of activities at the international level are performed.

SAS is of the opinion that some market-based measures should be set, at the condition to be well-balanced and defined. The company expresses a concern about inefficient instruments that could have a negative impact for the company's financial performance, which is largely affected by changes in fuel price. However, SAS seems to be proactive towards the implementation of some regulatory measures to spur renewable fuel implementation. This attitude is reflected in the various networking activities mentioned before.

Another important actor at the national level is Malmö Aviation, an airline company held by Braathens Aviation (also owner of another airline company, Sverigeflyg), providing mainly short-haul flights within Sweden. While acknowledging the future importance of biojets for the development of a more sustainable aviation system, the company does not plan to make use of renewable fuels, at least in the mid-term (Malmö Aviation, pers. comm., 2014). One of the reasons that justify this decision is the fact that the company is currently using aircrafts running on a different kind of fuel. These aircrafts are going through a fleet renewal process that might take a long time to be completed (Malmö Aviation, pers. comm., 2014). Apart from technological impediments, the main barrier that hinders use of biojet is the large spread between conventional fuel price and biojet price. Therefore, even with suitable aircrafts, the company would not purchase biojet that is significantly more expensive than fossil fuel.

Malmö Aviation is not involved in any biojet R&D project, and participation in associations such as NISA is not proactive (Malmö Aviation, pers. comm., 2014). On the other hand, the company performs lobbying activities on politicians with regard to air travel and environmental regulation (Malmö Aviation, pers. comm., 2014). Advocacy efforts aim to convince politicians to support the airline industry to adopt biojet by providing strong financial incentives and take a leading role in the transition.

Regulatory bodies

Regulatory bodies are the organisations whose prime function is to define laws and regulations by which companies must abide. The group includes authorities at the national, European and international level. Many of the actors in this area are agencies having an authority delegation on a specific topic.

At the national level, the administrative process is carried out by government agencies with a specific area of focus. Many of the Swedish national agencies involved in the biojet SI operate on behalf of the Ministry of Enterprise, Energy and Communication. The role of the Ministry is to steer the activities performed by the agencies in a general direction. For instance the Ministry, rather than giving specific targets to achieve, indicates the agencies how to funnel their funds for R&D activities. The agencies have to send the Ministry reports on the way they work, in order to make performance assessments and set their own priorities and goals. Networking, therefore, is an important task for agencies, because it highlights the most relevant activity areas that an agency deals with (STEM-b, pers. comm., 2014).

In a broad perspective, the government is not proactively involved in the biojet innovation process (TS, pers. comm., 2014); on the other hand, there is a high interest in the promotion and diffusion of road transport biofuels, which are considered easier to regulate and diffuse at the national level (STEM-b, pers. comm., 2014). However, the national authority would benefit from the implementation of local bioports in several manners: firstly, it would likely contribute to the economic development of the agricultural and industrial sectors; secondly, reducing aviation emissions would accelerate the achievement of national environmental targets; thirdly, it would reduce the country dependence on crude oil while increasing energy security; and lastly, it would contribute to the image of Sweden as a leader in research, production and use of sustainable biofuels, and as an exporter of knowledge and clean technology. A similar reasoning, albeit with intrinsic differences in magnitude, also applies for benefits at the European level. An international regulating body like ICAO, on the other hand, has some interests in common with the aviation sector, as it aims to foster the sustainable growth of air aviation industry.

The Swedish Energy Agency, or STEM, (*Energimyndighet*) is the entity administrating national energy policy issues for the creation of a economically and environmentally sustainable energy system (STEM, 2012b). This goal is pursued through the promotion of renewable energy sources and the implementation of secure and energy efficient installations. Moreover, STEM is the supervising authority over various aspects of environmental regulation of energy, including Swedish biofuel legislation. STEM activities are steered by the Ministry of Enterprise, Energy and Communication through the assignment of the budget. In addition, the activities performed must be in accordance with EU legislation (STEM-b, pers. comm., 2014).

One of the main groups of activities is the allocation of funds in various areas of development through funding programs for research and demonstration projects (STEM-b, pers. comm., 2014). STEM also performs operations related to the implementation of financial support systems for the diffusion of renewable-based energy such as biofuels. Both these groups of activities are connected to financing aspects, and will be therefore described in detail in section 3.4.1.

All in all, STEM argues that it has not much power to influence support to aviation biofuels initiatives. Although networking activities can be steered to a certain extent, research funding is dependent on the applications received. Therefore, STEM can give support to biojet research only if there is some interest from independent projects and organisations (STEM-b, pers. comm., 2014).

The other main entity administrating the area of biofuels is the Swedish Transport Agency, or TS (*Transportstyrelsen*), responsible of the transport sector management. The Agency's core activities include regulating the Swedish transportation, issuing grants and permits, market monitoring, knowledge dissemination and research support (TS, 2013). A specific department is in charge of the maritime and civil aviation sector administration. Apart from regulatory tasks, the department conducts environmental impact and emission calculation assessments, and is responsible of issuing environmental permits for airports (TS, pers. comm., 2014). Unlike STEM or Vinnova, TS has not budget allocated for the funding of research initiatives, but the tasks include networking with member states and associations to facilitate dialogue and information sharing, and other supporting activities (TS, pers. comm., 2014). Such collaborating activities are reflected in the cooperation with ICAO for the development of standards for aviation and biojets (TS, pers. comm., 2014), the participation in NISA, and the involvement in the Flightpath Initiative.

An agency that is partially involved in the biojet innovation process is Vinnova, the Swedish Governmental Agency for Innovation Systems. Vinnova's mission is to promote sustainable growth by improving the conditions for innovation and by funding needs-driven research (Vinnova, 2014a). In practice, the Agency encourages stakeholders' collaboration and supports various research activities. Vinnova is also the national contact with regard to the EU's Framework Programme for R&D (Vinnova, 2014a). The encouragement of collaborative programs is carried out through meeting of actors, initiation of learning processes, organisation of workshops and provision of resources to researchers following the development process. Within joint research programs, the Agency's contribution is mainly financial, and, besides studies performed to get a deeper understanding of the areas addressed, Vinnova does not conduct own research projects. Even though Vinnova contributes substantially to national innovation processes, activities related to biofuels are limited (Vinnova, pers. comm., 2014). A few biofuel initiatives within the program *Vinnväxt* are given financial support; among this already modest group, the share of biojet-related programs is small (Vinnova, pers. comm., 2014).

The International Civil Aviation Organisation (ICAO) is a UN specialised agency overseeing the global civil aviation. Its main function is to set standards and regulations for aviation safety, security, efficiency, regularity and environmental protection (Bacovsky, 2011). It is member states' responsibility to conform to ICAO international regulation when developing their legally-binding national laws. ICAO environmental committee, the Committee on Aviation Environmental Protection (CAEP), contributes to the formulation of new environmental policies and the setting of standards to reduce aviation environmental impact. CAEP board is composed of 23 members and 16 observers. Sweden is the only Nordic country with a membership in the board: this unique feature gives the ability to exert influence on regulatory work and international agreements (TS, pers. comm., 2014).

In recent times ICAO has increased its attention towards aviation environmental impacts and alternative fuels. A signal of this awareness is the announcement of implementation of a aviation market-based measure starting from 2020 (EC, 2014b). Within CAEP, the Alternative Fuels Task Force was recently established with the purpose of assessing the range of potential carbon emissions reduction from the use of biojet, and to define a methodology for the lifecycle analysis of alternative fuels emissions (ICAO, 2013; Velarde, 2013). The fact that ICAO is a UN agency in which many stakeholders with different interests get together slackens the speed of regulatory actions; however, thanks to its supranational authority, national governments are induced to sign bilateral agreements in accordance to ICAO regulation.

Research bodies

This group comprises the actors whose core activities are related to research and development on the topic. Members include universities, research institutes and groups, science parks, and so on. An itemised examination of the activities performed within this group has been provided in section 3.1.1. Universities and research institutes benefit from taking part in applied research activities by receiving funds from industry stakeholders and the government; moreover, successful results leading to commercialisation contribute to the prestige of the research centres.

Interest associations

Among the actors forming this group are found various associations with the purpose to influence decisions in any area of the SI in order to safeguard their members' interests. They can be sectoral representation groups composed by a number of companies belonging to the same industry, or NGOs performing specific advocacy activities. The former are often branch organisations like Svebio, Svenskt Flyg, and, at the global level, IATA and the Air Transport Action Group (ATAG); the latter can be heterogeneous groups formed by stakeholders with different provenience but common objectives (such as NISA), or environmental organisations.

IATA, ATAG and Svenskt Flyg represent the aviation industry at the international and national level respectively. These three associations have the role to protect the interests of their members within the groups in which they take part. Thereby, the associations' main task is to strongly advocate against measures that would limit the aviation sector growth, such as regulations imposing economic encumbrance on the industry.

IATA, representing the airline sector, and ATAG, including all aviation industry actors, are the most relevant private sector organisations (OECD, 2012). Being global-scale organisations, their description will not be detailed, but it is important to acknowledge the existence of these strong branch associations in the international arena. Both groups have expressed interest in finding a way to make aviation more sustainable while ensuring its economic development, and consider this issue a critical challenge for the future of the sector (OECD, 2012).

At the national level, Svenskt Flyg's role is to convey the requests from its members – which comprise the Aviation Industry Group (*Svenska Flygbranschen*), airport administrators and few others – to politicians and national agencies (Svenskt Flyg, pers. comm., 2014). Advocacy towards policymakers aims to ensure sectoral growth and economic development. Lobbying activities also target the press and the general public. Actions taken to ensure long-term sustainability of the aviation sector include advocacy efforts to address environmental sustainability of aviation. The association's claim is that, due to the current high cost of renewable fuel, the government should financially support its use, because the aviation industry cannot afford to bear the price of the new technology (Svenskt Flyg, pers. comm., 2014).

NISA is an association composed of several stakeholders interested in the transition to a more sustainable aviation in the Nordic region. Among the supply chain actors included in the association, three main groups can be distinguished: airline companies, airports, and manufacturers. Other stakeholders are branch organisations and public authorities (NISA, pers. comm., 2014). NISA members comprise influential stakeholders from the Swedish, Norwegian, Danish, Finnish and Icelandic aviation sectors. The association is organised as a consortium, in accordance to a recommendation from ICAO (NISA, pers. comm., 2014). NISA members are divided into two groups: core members, whose financial contribute is more substantial, are organisations directly involved in the aviation sector, and are also members of the board; associate members, who have lower financial duties, participating in the activities and dialogue but unable to become board members.

The main activities performed by NISA consist of supporting the process of putting sustainable aviation on the political agenda. By expressing interest in aviation biofuels, NISA aims to encourage actors to supply these products. By conducting national studies on biojet potential in each of the Nordic countries, the association's short-term goal is to get an overview of the available actors and the possible forms of collaboration among them on a Nordic scale (NISA, pers. comm., 2014). The long-term plan is to engage policymakers for securing the production of dedicated bioresources and establishing sustainable aviation practices in the Nordic (NISA, pers. comm., 2014). To achieve this goal, NISA conducts a dialogue with politicians regarding the provision of incentives to move this transition forward.

In accordance to its statute, NISA aims to catalyse the development of three pilot projects for local production of sustainable biojet and a business case for full-scale biojet production in the Nordic. The target for these projects is 2016. In addition, the association works to contribute to the 2 million tons of sustainable biofuels target set by the European Union (NISA, pers. comm., 2014).

Belonging to several stakeholder areas, NISA members are moved by different drivers that justify their interest in sustainable aviation. However, all these members would benefit from a reduction of carbon emissions from the aviation sector because of the international pressure that has been put on the air transportation industry.

Another group of interest organisations is constituted by NGOs involved in environmental matters. These organisations exist at both the national and international scale. In Sweden, a prominent role is played by the Swedish Society for Nature Conservation (in Swedish: *Naturskyddsföreningen*), in addition to several international organisations such as Greenpeace and the World Wildlife Fund. In a larger perspective, workers' associations, workers' and trade unions, employers' associations and consumers' associations might as well be driven by environmental concerns. These organisations are not directly involved in the biojet innovation process, but are stakeholders in the transition to a more sustainable society. Therefore, such NGOs are closely following the issue of biofuels in aviation and are developing their positions on the topic. Their opinion about biojet diffusion is not necessarily positive, as it might be argued that aviation is an energy-intensive sector whose growth should not be encouraged at all. This is particularly valid for domestic aviation covering short-haul distances that could be covered with more sustainable means of transportations such as trains. While certainly relevant, these issues fall outside the scope of this study. Moreover, several stakeholders claimed that NGOs' opinion on biojet has, at the current stage, no impact on its diffusion; further research is needed to assess these matters more in detail.

Concluding remarks

The biojet innovation process is being influenced by a vast number of organisations, especially among the different stakeholders in the supply chain. Due to the complexity of the biojet manufacturing process, producers are composed a very diversified group. Some important actors (Neste Oil, Statoil Aviation) are influencing the SI by creating incentives for development. The current scarcity of feedstock suppliers has created a potential business opportunity that could be exploited by actors such as the Paper Province. However, uncertainty in the market generates high investment risks that discourage potential entrants. Other main fuel producers like Preem could enter the market in the future, in case business occasions are identified. The market entrance of such a large and experienced actor would contribute to reduce the overall production costs, increase the production capacity and reduce market uncertainty. The presence of SkyNRG in the biojet market is a promising signal of the Swedish potential. SkyNRG is addressing the issue of scarcity of suppliers, providing further incentives to local biojet production.

Although the role of distributors is not central in the supply chain, airports can contribute significantly to biojet diffusion. Favourable conditions are given by the fact that airports are mostly run by state-owned companies driven by strong environmental concerns. With the start of the Karlstad Bioport project, a forerunner role is about to be played by Karlstad Airport, whereas Swedavia's potential has not been largely exploited yet. A relevant observation is that airports are bottlenecks for all air traffic, and a legislation targeting national airports to set environmental regulation would be an effective solution.

On the users side, contrasting signals about biojet diffusion can be observed. While all airline companies concur that sustainability of aviation should be brought up on the political agenda, there is disagreement about the role the airline industry should play. A first group of actors believes that airlines should have a leading role in the transition process, bearing part of the costs and acting proactively to push biojet forward. The second group acknowledges the long-term sustainability issue and recognises the importance of biojet with this regard, but believes that suppliers and the government should be the actors responsible for the transition. This duality in opinions is not a specific trait of the Swedish context, but can be seen as well at the international level. As a result of the difference of views, user groups do not have a clear strategy to tackle this issue. Aviation interest associations enjoying an influential position do not provide strong contribution to the transition process because of this reason.

The work of national regulatory bodies is dependent on government interest in sustainable aviation, which is at the current stage limited. The existence of agencies as Vinnova and STEM is very important for the innovation system, but their activities should be steered towards biojet research and support. Likewise, the presence of the Transport Agency as the body regulating aviation has a positive impact, but its operations and power are not sufficient to make a significant change in the status quo. At the global level, ICAO could be a powerful actor in fostering the transition to sustainable aviation, but its decisions are influenced by many contrasting interests, leading to seesawing results. A fundamental actor for the success of the innovation process is NISA, which has the important role to draw government's attention towards sustainability of aviation through advocacy efforts and diffusion of information.

3.3.2 Networking

As discussed in section 2.3.3, networks play a central role in the Swedish biojet innovation process. According to the literature, actors have several benefits from establishing networks, including: risk sharing; access to new markets, technologies and external knowledge; synergies from complementary skills; protection of property rights (Pittaway, Robertson, Munir, Denyer, & Neely, 2004). Among the many benefits provided by networks in the biojet SI, one is that their presence facilitates knowledge transfer and competence building, creating a dynamic environment characterised by information sharing and labour force movement across the actors in the market.

Networking activities are not easy to categorise, due to the heterogeneity of actors in the innovation system and the numerous types of relations among them. Moreover, some business-to-business relationships and informal networking are very difficult to pinpoint and describe. To ease the presentation of networking activities in the innovation system, three main classes have been identified: networking between companies on the same level of the supply chain (intra-group networking); networking between companies on different levels of the supply chain (inter-group networking); networking between stakeholders with different roles (companies, regulatory bodies, research groups, and so on).

Intra-group networking

The first class of networking activities describes the relations among companies that lay in the same level of the supply chain; that is, within the producers, distributors or users group. On the one hand, these companies have similar business activities, and are therefore potentially competing with each other; for the same reason, on the other hand, they have similar interests and challenges, so their instances and needs can be addressed through mutual collaboration. Branch organisations, in particular, represent the interests of companies belonging to the same layer of the supply chain, and are responsible for unifying companies' needs and conveying their demands onto a larger playing field.

As illustrated in the previous section, the producers group includes actors with partially different core activities. Since among these actors the competition problem does not arise, several networking activities exist. One example is given by the collaboration of Statoil with SkyNRG and its well-established business relationship with Neste Oil (Statoil Aviation, pers. comm., 2014).

The fact that Swedavia, a state-owned company, administers the majority of the biojet distribution activities has an impact on the networking activities within the distributors group. Besides Swedavia's interest in Karlstad Airport activities, no relevant networking activities within the group can be found. Many of the small private-owned airports are members of the Swedish Regional Airports (*Svenska Regionala Flygplatser*) group, but this type of network does not relate to aviation biofuel. It can be argued that, given that the role of distributors in biofuel sale is mainly to provide adequate infrastructure and facilitate trade between producers and users, airports do not have incentives to network among them, but rather with other supply chain actors. The small number of distributors involved in biojet diffusion is another deterrent for networking. Therefore, Swedavia and Karlstad Airport's focus is on inter-group networking rather than intra-group networking.

Within the users group, SAS is a promoter of intra-group collaboration for sustainable fuels commercialisation (SAS, pers. comm., 2014). The rationale behind collaboration is that even though airlines are market competitors, all companies would benefit from a developed and cheap biojet technology. Hence, the need to collaborate to achieve better results overcomes barriers created by competition. The Aviation Industry Group permits this type of cooperation, but most of the dialogue is carried out within NISA, because it involves the participation of other important stakeholders. Thereby, although there are no obstacles for intra-group networking, larger forms of collaboration are usually prioritised.

Inter-group networking

The second class of networks consists of the activities between companies at different levels of the supply chain. In other words, these are networking activities among the producers, distributors and users groups. Handling the relationships with companies that lay upstream and downstream in the supply chain is an important aspect of inter-organisational management. Understanding each other's perspectives and challenges is fundamental for identifying weak points in the supplying process, and the synergies that could be achieved with cooperation. Looking at the biojet production process, it can be argued that networking among different supply chain actors contributes to increasing the efficiency of the production process and strengthening the value chain.

Producers, distributors and users can bring together their different skills and expertise and use them in a complementary fashion to achieve more than they would accomplish on their own. Examples of the increased value from collaborative initiatives are provided by the joint research and demonstration projects in general, and the Karlstad Bioport project in particular. In the latter, various stakeholders contribute to the Bioport development: feedstock providers (the Paper Province), fuel producers (SkyNRG, Statoil), distributors (Karlstad Airport). The Paper Province and Karlstad Airport are attempting to enlarge the Bioport network by engaging more actors for a local supply chain development. For example, the Paper Province is organising closed business meetings with local stakeholders aiming to inform about possible economic returns of establishing a biojet supply chain (Paper Province, pers. comm., 2014).

Apart from the activities in Karlstad, another collaboration project the one presented in the previous section being conducted in Arlanda Airport with the collaboration of Swedavia, Solena and other actors. On a general level it can be noted that several initiatives see the collaboration of various stakeholders, because of the different kind of expertise and resources they can provide.

Networking among different stakeholders

The third class of networking activities includes the relationships and collaborations between the actors in the supply chain and other stakeholders in the innovation process, such as regulatory bodies, research groups and interest associations. An effective networking at this scale is determinant for the success of the whole innovation process, because it puts the supply chain companies into a larger context of actors.

The assertion about creation of synergies and mutual understanding of perspectives and challenges discussed for supply chain inter-group networking is even more valid for networking performed by a heterogeneous group of stakeholders. The identification of common purposes can lead to activities for the improvement of the overall biojet SI.

Research has great benefits from this type of networking. In collaborative research activities, each actor contributes to the effectiveness of the research process: the research bodies are steered by the industry actors, which give a guidance about the areas where research is needed and can result in practical outcomes. Government agencies also have a role in this type of network: through a dialogue with the supply chain actors they define national priorities and provide financial and informative assistance to research projects. The projects often see the participation of more than one agency at the same time; these are usually STEM, TS, Vinnova and the Swedish Environmental Protection Agency (*Naturvårdsverket*) (STEM-b, pers. comm., 2014). In the field of biofuels, the actor promoting such networking activities is the f3 centre, which, receiving funds from STEM, establishes biofuel groups (such as the thermochemical and the gasification groups) and provides in turn funding for research (STEM-b, pers. comm., 2014). No networking group for biojet has been established yet. However, representatives from STEM affirmed that a so-called "flight meeting" group is in the process of starting to operate. Other than STEM, this networking group will include actors like TS, Swedavia, and NISA, aiming to identify possible fields of development for aviation biofuels (STEM-b, pers. comm., 2014).

Some government agencies might not participate in heterogeneous networking groups, but have strong connections with other public authorities. Vinnova, for example, is not involved in projects with supply chain businesses, but collaborates in many ways with other authorities and financing organisations (Vinnova, pers. comm., 2014). STEM has also similar connections with other government bodies.

A strong biojet network including various types of stakeholders is established through NISA activities, as described in section 3.3.1. Since the focus of the initiative is at the Nordic level, international linkages are established, not just with Norwegian, Danish and Finnish actors, but also with organisations with a global scope and similar regional biojet networks such as the German AIREG and the British *Sustainable Aviation*. In this manner, synergies with other Nordic stakeholders are identified, knowledge is shared, and common issues and solutions are discussed. *Green Aviation Days 2014*, a conference organised by NISA in September 2014, was designed to enhance Nordic and international cooperation.

Concluding remarks

Many connections among organisations can be observed in the innovation system. In the intra-group dimension, strong linkages within the producer group and the user group can be found. The fact that the majority of air travel involves airports run by Swedavia implies that networks among airport companies have a lesser importance, although the transition process could be fostered through the sharing of information regarding best practices and innovations. Networking can also be observed in an inter-group perspective, with some noteworthy initiatives involving various supply chain actors – notably, the Karlstad Bioport project. Such activities have a great impact in diffusing knowledge, raising awareness, enhancing supply chain management, and ultimately fostering biojet deployment. For these reasons, they should be further encouraged. Concerning networking among different stakeholders, various activities, mainly targeting the creation of research projects, have been identified. Government agencies play an important role in this type of collaborations by facilitating companies and research bodies come together; for this reason, they should expand their networking with stakeholders. A positive signal is given by new initiatives composed by a diverse group of stakeholders addressing aviation sustainability; these initiatives should be further encouraged.

3.3.3 Institutions

A series of key activities determining the success of the innovation process are related to system institutions. As discussed in section 2.3, institutions constitute all forms of rules (from official regulation to embedded behaviour costumes) that affect the actions of actors in the innovation system; in other words, they form the background environment in which organisations operate.

Laws and regulations

A problem arising from the use of a taxonomic classification system is limiting the presentation of a group of activities within the designed categories. This is particularly problematic for institutions, because laws and regulations have a large impact on various other key activity groups, such as financing and target setting. As a result, institutions are spread across the diagnostic analysis. To follow the categorisation method, it has been decided to discuss this section by presenting a recapitulatory list of key system institutions. Therefore, a list of most relevant laws and regulations is compiled in Table 5. The table indicates the regulation main features, the issuing or administering body, and, whenever possible, the section in which the regulation has been discussed.

Table 5. Key system institutions.

Name and main features	Responsible body	Related activity group
Renewable Energy Directive (2009/28/EC) Sets a series of targets for RES energy supply to reach by 2020 in Europe (20%) and Sweden (49%). RES transportation sub-targets are also set. Sustainability criteria and a GHG calculation method for biofuels are defined.	EC	New product markets (3.2.1); Quality requirements (3.2.2).
Emission Trading Directive (2009/29/EC) Amends Directive 2003/87/EC. Establishes and regulates a European Emission Trading Scheme (EU-ETS) for energy-intensive industries with the purpose to reduce overall emissions.	EC	New product markets (3.2.1)
Aviation Directive (2008/101/EC) Amends Directive 2003/87/EC. Includes the civil aviation sector into the EU-ETS for emissions allowance trading.	EC	New product markets (3.2.1).
Amended Fuel Quality Directive (2009/30/EC) Amends the Fuel Quality Directive 98/70/EC. Establishes low carbon emission standards for road transport fuels. Defines sustainability criteria for biofuels.	EC	N/A
Energy Taxation Directive (2003/96/EC) Sets the Community framework for the taxation of electricity and energy products, defining minimum levels of taxes for energy carriers. Supports efficiency in energy use and allows member states to set tax exemptions for low-carbon energy sources. As the regulation is considered outdated, possible revisions are currently debated.	EC	New product markets (3.2.1); Financing of the innovation process (3.4.1).
General Block Exemption Regulation (EU) No. 651/2014 Substitutes Regulation (EC) no. 800/2008. Determines categories and conditions for the provision of state aid within the Community, defining eligible beneficiaries and expenses and maximum aid levels.	EC	R&D results (3.1.1); Financing of the innovation process (3.4.1).
Act (2010:598) Concerning Sustainability Criteria for Biofuels Applies at the national level the European legislation and establishes a set of criteria for determining if a fuel is considered sustainable in Sweden.	STEM	New product markets (3.2.1); Financing of the innovation process (3.4.1).
Act (1994:1776) Concerning Taxation of Energy Sets national rules for taxation of electricity and energy products, enabling tax exemptions for low-carbon technologies including biofuels.	STEM	Financing of the innovation process (3.4.1).

Fuel Quality Act (2011:319) Imposes on fuel suppliers certain requirements on fuel specification and reporting, with regards to fuel origin, volumes and emission performance.	STEM	N/A
Government Bill 2008/09:162 and 2008/09:163 Set a number of targets and strategies for Sweden, in line with the 20/20/20 targets.	Swedish Parliament	New product markets (3.2.1).
Government Bill 2010/11:152 Requires the compilation of a sustainability statement to obtain tax exemptions for sustainable fuels.	Swedish Parliament; STEM	N/A
Chicago Convention Establishes ICAO as the UN regulatory body overseeing international civil aviation. The Convention and its further amendments set a specific tax exemption on aviation fuel.	ICAO	Financing of the innovation process (3.4.1).

Source: own elaboration, based on EC (2008a, 2009a, 2011b); ICAO (2010); Pobłocka (2013); STEM (2011, 2012a, 2013a, 2013b); Swedish Government (2013).

Embedded norms

Laws and regulations build the legislative structure under which organisations act and relate among each other. However, the category of institutions also comprises all the forms of norms, cultural beliefs and social rules having an impact on organisations. These norms, which are sometimes not formalised, constitute a resilient social fabric determining the means of interactions between actors. Evidently, some of these forms of institutions are very hard to identify and to describe. While acknowledging the existence of many norms embedded in society and the business environment, this section will mainly address explicit and identifiable cultural traits.

A first area of discussion regards intellectual property rights, which are legally protected in Sweden. Intellectual property laws cover patents, trade names, copyrights and trademarks issues. Intellectual resources can also be sold or licensed. A patent, which provides a sole right to use an invention, usually costs 50 000 to 70 000 SEK (5 400 to 7 600 EUR) and lasts 20 years (EU, 2012). However, it should be noted that research grants issued by government agencies state that discoveries achieved through the support of public funding are of public domain. The process of applying for a patent is supported by the state-owned organisation Almi Företagspartner (see section 3.4.1). All in all, the presence of an accessible system to protect intellectual property rights encourages the creation of new inventions.

While relations among businesses have different characteristics, some common features in the relationships between universities and business firms can be noted. Researchers' interactions with business companies occur through their academic position. However, unless a specific research program is set by the university, professional consultancy activities with firms are performed part-time, due to temporal limitations of researchers' role (Brundenius et al., 2011). Because of this, long-lasting informal relationships between academics and businesses are seldom established. However, an important factor affecting the collaboration between universities and private companies is the so-called "third mission" of Swedish academics. Swedish universities, in addition to education and research activities, have the role to support the overall economic and social development and facilitate the sharing of academic knowledge to non-experts (Brundenius et al., 2011). Therefore, Swedish academics are highly encouraged to assist commercial activities with their expertise. This is reflected in the many collaborations between universities and private businesses that have been presented in section 3.1.1. According to Brundenius et al. (2011), the attitude towards the third mission varies considerably among different universities. It is observed that the third mission is highly valued among small universities, due to the need of establishing relationships at the local level and the search of funding partners.

A distinguishing feature that can be noted from the analysis of organisations involved in the innovation process is that many companies are entirely or partially controlled by the public authority. The fact that the state participates in the company's management entails that decisions are not only taken in economic terms, but also with the aim to contribute to the overall societal wellbeing. This aspect is often reflected into strong concerns in the company's environmental performance, and acts as a driver for innovation. As state ownership is present at all levels of the supply chain – among producers, airports and airlines – it can be asserted that this feature can facilitate the relationships among the actors and the overall support to technological change.

As a country characterised by a diffused environmental awareness, Sweden is deemed to be a favourable context for the development of cleantech innovation. This is further encouraged by the role played by the Swedish government as a driver of environmental concerns worldwide. However, many stakeholders in the SI perceive an overall disbelief in the possibility of aviation to become sustainable; scepticism is seen both among politicians and the general public. This aspect might prove to be an obstacle for convincing policymakers of the usefulness of fostering biojet deployment, as well as for obtaining the public support from NGOs and individuals. The perceived scepticism, however, is not backed by substantial evidence, but has simply been pointed out by some actors from the airline industry; further research is needed to assess the legitimacy of this argument.

Concluding remarks

Institutions, providing a contextual setting for organisations' actions, play an important role in the innovation process. Plenty of laws administering biofuel and its environmental performance can be found at the national and European level. This regulation, however, is not absent of shortcomings, which need to be identified and mitigated. Changes in legislation, however, require long time spans, because national and European laws issued by policymakers depend on a slow negotiation mechanism. It is also noticed an inadequate legislative framework concerning aviation sustainability issues, which are regulated by ICAO rather than European norms. Again, legislative changes may occur and should be encouraged, but they will take a considerable amount of time to become effective.

With regard to Sweden's embedded norms, values and cultural rules a few conclusions can be drawn. Although the analysis of these factors belongs to social science research and has not been thoroughly inspected in this study, it can be argued that few significant barriers to the innovation process have been identified. On the contrary, some aspects show that the Swedish context provides a suitable environment for innovation. As noted, embedded norms are the most resilient and difficult to change, and the fact that they provide drivers to change rather than barriers is certainly a positive aspect.

3.4 Support services

3.4.1 Financing of the innovation process

The objective of this section is to present the financial aspects of the biojet innovation process. In order to establish the newly created production process, the system of innovation has to be provided with an adequate amount of capital for investment. In addition to that, some actions need to be taken to ensure early stage market competitiveness of the innovative product. These two aspects will be discussed, and the organisations providing the two types of financial support will be identified.

Initial capital raising

As the formation of the biojet supply chain requires to make investments for research, infrastructure, logistics and labour force, it is paramount to ensure the availability of initial capital for supporting the innovation process. The investments discussed in this section are those necessary to start innovative projects in the small scale, while the task of increasing size of operations is left to the actors. Clearly, scaling up plants is a crucial step to increase capacity and create a strong business case; but this aspect relates to the issue of reaching market competitiveness, which is examined in the following paragraph.

The most influential actors in the jet fuel supply chain consist of large companies with high turnovers; this assertion is valid for producers, distributors and users. Therefore, it can be argued that, for these actors, initial capital raising for a remunerative investment is not a problematic task, and, to a certain degree, it can be performed without resorting to an external actor (SAS, pers. comm., 2014).

Actors that lay outside of the supply chain and small-scale feedstock producers, however, do have limited access to capital. Research bodies and innovation-focused SMEs, in particular, struggle to finance new projects with their own funds, and rely on third parties to provide financial support to their operations. The two main categories of funding actors that give this kind of support are businesses belonging to the supply chain and government agencies. In the first case, the research or demonstration project usually leads to an outcome that provides direct or indirect advantages to the funding company. This is for example the case for SAS, which provides financial support to research initiatives and innovative projects (SAS, pers. comm., 2014). In the second case, funding is provided by the public authority in the form of grants. The objective is to individuate worthy projects and support them because of their high research potential, to steer research towards a specific area of study or to spur the growth of pioneering businesses.

Provision of financial state aid is regulated at the European level by Commission Regulation (EU) No 651/2014, also known as General Block Exemption Regulation, or GBER (EC, 2008a, 2014a). This regulation has been recently updated, and will come into force in 2015. Thereby, it is hard to identify the changes from the previous regulation (STEM-b, pers. comm., 2014). The GBER categorises state aid into several areas and sets maximum aid levels in relation to the type of area, industry, research and business size (EC, 2008b). The Swedish authority applied this legislation at the national level with the Ordinance 2008:761 on state aid for research and development and innovation in the energy sector (in Swedish: *Förordning om statligt stöd till forskning och utveckling samt innovation inom energiområdet*). In accordance to this regulation, the two main national authorities responsible for provision of funds to research, development and innovation to the industry sector are Vinnova and the Swedish Energy Agency (Committee on Subsidies and Countervailing Measures, 2011). At the regional level, additional financial aid to R&D projects could be granted by County Administrative Boards (Committee on Subsidies and Countervailing Measures, 2011).

As introduced in section 3.3.1, an important role in the process of funding innovation in Sweden is played by Vinnova. The Agency, through the *Support for Technological R&D&I* program, administers the provision of funds to enhance research, development and innovation initiatives (Committee on Subsidies and Countervailing Measures, 2011). Support is given in the form of direct grants or soft loans with conditional repayment through a variety of projects. Financial aid is targeting universities, research institutes, firms and inventors. The research funding activity is supported by a very organised assessment process, which is usually performed with the assistance of external evaluators (Vinnova, pers. comm., 2014). A condition for receiving the grants is that all the results of the research projects have to be made public.

One of the supporting projects, the *Vinnväxt* program, sponsoring sustainable growth in regions, started in 2001 and has issued four calls for proposals since, awarding each winner 1 million SEK (109 000 EUR) per year over a period of ten years (Vinnova, 2014b). Among the winning projects there are the Biorefinery of the Future and the Paper Province. The former and the latter have been introduced in sections 3.1.1 and 3.3.1 respectively.

In 2013 Vinnova funded around 2.4 billion SEK (260 000 EUR) in overall R&D activities (Vinnova, n.d.). Considering that research grants can provide up to 50% of the project initial investment cost, it is assumed that co-financing from actors involved in the projects accounted has been at least the same amount. Ultimately, Vinnova does not just provide financial support to research projects, but also encourages private investing in innovation.

STEM is the other body responsible of providing state aid to research and innovation at the national level, in accordance with the European legislation. STEM, as discussed in section 3.1.1, has several regulatory tasks, including the allocation of funds for development in the energy area. This is carried out through the *Energy Research Programme*, in which STEM is the main administrator but not the only public actor involved (other contributing agencies are Vinnova, Formas and the Swedish Research Council) (Committee on Subsidies and Countervailing Measures, 2011). The Programme provides mostly grants with the goal of supporting research, development and innovation in the national industry; environmental protection is a secondary objective (Committee on Subsidies and Countervailing Measures, 2011). As for the *Support for Technological R&D&I* Programme, all results from research are official and shall be made available to the public. The grants cover up to 50% of the eligible costs, which include personnel, materials, supplies related to R&D, instruments and equipment, consulting, etc. (Committee on Subsidies and Countervailing Measures, 2011). However, the 50% grant is given only to projects that are far from the market; projects closer to a market-competitive business are usually given grants covering around 25% of the cost (STEM-b, pers. comm., 2014). Support is given to universities and academia, public-private research institutes, and undertakings. The fact that part of the funds is given to universities is to increase their level of independence in research activities (STEM-b, pers. comm., 2014).

According to a STEM representative, the financing provided by the Agency addresses research on biofuels and fuel consumption, while aviation and biojets are not specifically targeted (STEM-a, pers. comm., 2014). The selection process undergoes the decision of a board, which takes into consideration the whole lifecycle perspective, including the choice of feedstock used for biofuel production. The projects with the highest potential are awarded the funding. However, over a considerable period there has not been a specific funding program with regard to biofuels. Thus, rather than choosing among several alternatives, applications are received on an individual basis and compared to applications belonging to other fields (STEM-b, pers. comm., 2014). Of these applications, a small amount belongs to the aviation biofuel area. There is a mixed perception of future biojet programs among STEM representatives: some believe that interesting projects are starting to develop, others argue that it is too early to see a diffusion of these projects (STEM-a; STEM-b, pers. comm., 2014).

The funding program has an additional consulting function through which expertise is given to projects asking for support (STEM-b, pers. comm., 2014). STEM uses this assistance service to help projects understand their challenges and potentials. The consulting service, although valuable, has no success in reducing the problem of uncertainty of investments in bioresources, which, according to STEM representatives, is the main obstacle to overcome (STEM-b, pers. comm., 2014). Currently, the amount of funding provided by STEM is not sufficient to cover the risks of investing in an innovative field such as bioenergy (STEM-b, pers. comm., 2014). The industry itself is characterised by a high degree of risk: for instance, the pulp and paper industry needs to keep its plants producing full-time in order to generate profit, and cannot afford to reduce or stop the production. This means that long-term usability of the feedstock should be assured, in relation to both the demand and the legislative framework (STEM-b, pers. comm., 2014).

Innovative SMEs struggling to raise initial capital to start new projects can resort to other sources of state aid. Government support to SMEs is provided through the state-owned company Almi Företagspartner. The company is the Swedish representative of the Network of European Financial Institutions for Small and Medium Sized Enterprises (NEFI), whose goal is to provide access to finance to European SMEs. Almi supports innovation by providing loans, venture capital, advisory services and incubation programs (NEFI, n.d.).

Loans are given to projects characterised by high uncertainty levels that are unable to find financers among private investors. High-risk investments, however, correspond to high interest rates for the loan. Financing options include loans that are tailored for innovators; the provision of financial capital is carried out in cooperation with other credit providers, such as banks. As an alternative to loans, Almi provides venture capital for worthy innovation projects. Through the program *BIG Sweden,* Almi assists business incubators for innovative SMEs. These incubators offer facilities and infrastructure to support research projects; support to business incubators is given based on performance levels. Some of these incubators, such as Umeå Biotech Incubator, support specifically biotechnology research. Lastly, in addition to providing finance and the incubator program, Almi offers advisory services to innovation projects to help define, verify, develop and commercialise business ideas.

Early stage market competitiveness

Despite the growing interest in renewable jet fuel among end-users and the establishment of an early-stage biojet supply chain, the current demand for biojet in the market is very limited, due to its significantly higher market price in comparison to conventional fuel. This is because of the market failure occurring when the environmental costs of fossil fuel production and use are not fully accounted in the market price (STEM, 2012a). In order to have a fair market competition, it is necessary to level the playing field: this can be achieved through the application of various policy measures adjusting the demand level and the market prices. As asserted in the literature, support policies for biofuel development consist of two main alternatives: subsidisation or prescription of a mandatory production (Wiesenthal et al., 2009). Policy efforts to generate a biojet demand through the setting of targets and mandates have been discussed in section 3.2.1. This section analyses the existing policies supporting the penetration of biofuels in the jet fuel market through the provision of financial incentives.

According to the WTO definition, a subsidisation occurs when: the government provides direct transfer of funds, or potential direct transfer of funds or liabilities; a revenue is foregone or not collected; the government provides goods or services or purchases goods; the government provides income or price support (Charles & Wooders, 2011). In practice, market subsidisation of a product can be done directly, through disbursement of budget money (direct subsidy), or indirectly, through a tax exemption to the product or higher charges on competing products.

Direct subsidies for the diffusion of biojet could target the final product (aviation biofuel), or intermediate inputs in the supply chain (feedstock) (Charles & Wooders, 2011). At the current stage, no direct subsidy to feedstock or biojet is in place. This factor is not likely to change in the near future, considering that the Swedish authority is perceived to be reluctant to give subsidies to aviation biofuels. According to the Swedish Transport Agency, some stakeholders do not consider aviation a priority for the allocation of biomass: subsidies to biojet would give financial aid only to a little fraction of biofuels, whose varieties, in their opinion, should be all equally supported (TS, pers. comm., 2014).

Indirect subsidies are easier to implement, because they do not need to allocate part of the budget money to a specific purpose. Tax exemptions are a good example of this phenomenon. However, tax exemptions generate a decrease of total tax revenues, so the final impact on the national budget does not necessarily differ from direct subsidies.

Energy and carbon dioxide taxes in Sweden are levied on supply, production and import of fossil fuels. However, a special tax deduction for biofuels is in place, exempting suppliers, producers and importers of renewable energy products. The tax exemption is regulated at the national level by *Act* (1994:1776) *concerning taxation of energy* and Act 2010:598, applying the European regulation set by the Energy Taxation Directive (2003/96/EC) (Pobłocka, 2013). Being an indirect subsidy, the costs of such tax relief are borne by the state. To be eligible for the tax deduction, biofuels must be certified according to sustainability criteria defined in Act 2010:598. The amount of tax deduction is up to 89% (for petrol) or 84% (for diesel) of energy tax and 100% of CO_2 tax on the share of biomass-produced fuel, but only up to 5% by volume of the total amount of fuel (Pobłocka, 2013). The support is not technology neutral, and in some cases this figures are considerably higher (Riksrevisionen, 2011). The tax exemption framework targets low-level blending and has been an effective (but not necessarily cost-effective) measure to quickly introduce large volumes of biofuels into the market (Riksrevisionen, 2011). However, the regulation does not include biojets into the scheme, but is limited to conventional biofuels such as ethanol and biodiesel.

Stakeholders have proposed a number of measures to incentivise the diffusion of biojet through alternative forms of tax exemptions. These propositions are mainly based on the removal of the VAT or the landing fees for flights using sustainable fuels (Statoil Aviation, pers. comm., 2014; Svenskt Flyg, pers. comm., 2014). Fees on flight operations currently account for circa 40% of the total costs; according to SAS representatives, setting slightly lower fees for companies flying on blended fuel would provide a great incentive for biojet use (SAS, pers. comm., 2014). However, it appears to be difficult to convince policymakers to set lower national budget funds as a result from the loss of tax revenues.

To overcome the problem of obtaining budget money, a closed taxation-subsidisation system could be implemented. Companies with poor environmental performances have to pay an extra tax, which is used to subsidise well-performing companies. This bonus-malus system would have to be cautiously designed in relation to defining sustainable performances (SAS, pers. comm., 2014). The fact that many airlines are against a similar measure is a main issue preventing the implementation of this scheme.

A unique feature of the air transportation is the special tax exemption regulation on aviation fuels. This regulation was introduced by the Chicago Convention in 1944 and defined in ICAO's Document 8623, stating that jet fuel sold for international aviation is exempt from taxation (ICAO, 1944, 1951). Even though this regulation is not legally binding, it serves as a guideline for international agreements, as can be noted from the vast majority of bilateral agreements regulating civil aviation that exempt biofuel from taxes (Norberg, 2014). In substance, to impose a fuel tax on aviation seems to be a too difficult task. However, it should be highlighted the difference in ICAO's definitions between taxes and charges, the former being levied to increase state revenues and to be used for non-aviation purposes, the latter being levied to be used to reduce other costs of civil aviation (ICAO, 1951; Norberg, 2014). In light of this, a quota obligation system or a closed taxation-subsidisation system for aviation are considered charges, and are therefore feasible with ICAO regulation.

An interesting financing mechanism to bridge the price gap between conventional jet fuel and sustainable biojet is the Fly Green Fund. The FGF, planned to be launched in October 2014, will be used in the Karlstad Bioport project to allow price equivalence between non-blended jet fuel and various blends of biojet fuel and jet fuel. Airline companies will be able to purchase blended fuel at conventional fuel market price because the extra cost of biojet will be covered by the FGF.

The FGF is expected to be financed by voluntary donations from various stakeholders, including private companies, interest associations, national governments, local communities and individuals. The donations would show the commitment of actors to increase the sustainability of aviation. Karlstad Airport believes that the FGF can be administered by IATA, which would be responsible to handle the money inflow and outflow (Karlstad Airport, pers. comm., 2014). In alternative, the FGF could be also managed by SkyNRG, since it is the company providing biojet (Karlstad Airport, pers. comm., 2014).

Even though the fact that the FGF relies entirely on voluntary donations might compromise its effectiveness, Karlstad Airport is confident to obtain a sufficient amount of capital (Karlstad Airport, pers. comm., 2014). Such optimism originates from the great success that the FGF had in the Almedalen Week political forum in June 2014, in which many stakeholders, among which SAS, Swedavia and Braathens Aviation, expressed their interest in the initiative (Karlstad Airport, pers. comm., 2014). As a measure to offset carbon emissions, the investment is deemed attractive for airline companies (SAS, pers. comm., 2014). SAS believes that although bridging the price gap is a big challenge, many benefits would arise from its implementation. Swedavia representatives confirmed the worthiness of the initiative, arguing that such funding could be easily communicated to customers (Swedavia, pers. comm., 2014). However, Swedavia's ACA carbon neutrality certification is performed through specifically approved CDM investments, and substituting them with investments in the FGF fund would compromise the certification. Clearly, both investments could be done, but this would entail a higher expenditure (Swedavia, pers. comm., 2014).

The FGF is an interesting case of financing biojet market competitiveness with the sole contribution of private money. The effectiveness of the FGF cannot, at the moment, be assessed, but its launch demonstrates that some actors are actively involved in the promotion of biojet. Evaluating the performance of the FGF initiative will also allow to draw some conclusions on whether the interest in sustainable aviation is factual or only ostensible.

Through the FGF, stakeholders at the national and international level will be able to prove their commitment in pushing forward the diffusion of alternative jet fuel.

Concluding remarks

From the overall examination of the actors involved in the innovation process, the issue of initial capital raising for small-scale investments do not seem to be an overwhelming problem. The organisations needing financial support can find assistance provided by a series of stakeholders, including public bodies. The amount of support provided by agencies and Almi Företagspartner is significant, although this support does not necessarily target biojet-related projects. Whether or not a sufficient amount of capital is provided to these projects is difficult to assess.

Reaching early stage market competitiveness is deemed a more problematic issue, since biojet price is not competitive at the current stage of development. Indirect subsidies in the form of tax exemptions are provided to conventional biofuels, but biojet is not included in the tax relief scheme. Advocacy efforts should be undertaken to extend the tax exemption to aviation biofuel. This is a more realistic and justifiable objective than asking for specific direct subsidies to biojet production and use. In addition to that, the suggested alternative forms of tax reductions are interesting proposals that should be evaluated more in detail. Among this group, a closed taxation-remuneration system appears to be a noteworthy solution, because it is relatively simple to implement and does not entail an additional economic effort from the government. The main obstacle to this system is represented by the unwillingness of part of the airline industry to implement the scheme. Lastly, initiatives such as the Fly Green Fund are very promising methods to establish a framework to gather both private and public financing, and should be supported by all biojet stakeholders.

4 Discussion

The purpose of this Chapter is to zoom out from the immediate subject of this thesis and, apart from conducting an overall evaluation of the research, to discuss the suitability of the selected research approach, the study significance and its validity.

4.1 Framework suitability

The System of Innovation framework has been chosen for this study over a few alternatives for a number of reasons that are described in section 2.2. The purpose of this section is to examine the suitability of using the SI framework for the analysis of the biojet innovation process, identifying shortcomings deriving from its use and comparing them to its strengths.

As noted in section 1.2, the wide amount of research and debate conducted on the SI framework at the theoretical level does not find corresponding volumes of its practical application on existing case studies. Thereby, although precise information regarding conceptual approaches, categorisation methods and activity groups can be retrieved from the literature, the utilisation of the framework to describe the biojet innovation process encountered a number of issues.

First of all, innovation processes comprehend a wide range of technological transitions, spanning from firm-specific business ideas to sectoral changes having an impact at the global level. Since innovation processes can be very different among each other, SI theory has to keep the methodological discourse at a very general level; this creates a lack of precision in the definition of system constituents. Hence, it is the duty of the individual study to define with more accuracy the system components and characteristics. The framework, however, does not provide adequate assistance to identify these components. In substance, little information about how to recognise organisations, institutions and activities that have (or might have) a role in the innovation system is specified. The fact that some components might be overlooked in this process is a visible flaw of the SI framework.

In a similar fashion, the abstraction of the theoretical framework precludes the provision of clear indications on how to identify which activity groups are the most important in the innovation process. Therefore, recognition of the key activity groups has to be performed through stakeholders' opinions and overall assessments. Even though this can lead to subjective conclusions, the intrinsic difficulty of giving precise indications for features that vary from case to case is acknowledged.

The major problem encountered in the application of the framework is the issue of categorising the innovation system into separate activity groups. In the methodology section it was attempted to define the boundaries of each activity group and to customise the theoretical framework to the characteristics of the biojet innovation system. However, this description has not been sufficient to comprehend all the features of the innovation process. As any modelling approach is not fully able to categorise and describe reality and remains indeed a model, the SI framework does not allow to grasp the overall innovation system essence of dynamic arena in which activity groups influence each other and strong connections between different areas exist. This feature results in an overlapping of activities among the groups, generating repetitions and inconsistencies with the categorisation method, problems that are particularly evident in many activity groups such as *R&D results*, *Institutions* and *Networking*.

All in all, it can be argued the SI framework has been suitable for this study to a certain extent, but with some significant limitations. Its characteristics fit very well the necessities of having an interdisciplinary and evolutionary perspective and of using a framework in which both organisations and institutions play an important role. Moreover, the SI approach is very well developed at the theoretical level, and the existence of many different academic works allows to have various framework interpretations, which consents to customise the framework to the study needs. However, the large focus on theoretical discussions constitutes an issue since it creates a gap between theory and practice, resulting in problems that arise from its concrete application to a case study.

4.2 Interpretation of results and linkages between activity groups

The aim of the study is to present the innovation system status and features, and to assess the key system components for further development of the innovation process. For each activity group analysed, these results have been summarised in the concluding remarks of the related section. Because of this categorisation system, however, the results appear rather fragmented. To look at several aspects of the innovation system is useful for the analysis of the single aspect. In this manner, the status of each area of analysis, and its drivers and barriers, are discussed. This answers to a large extent the first and the second research questions.

Having an overall picture of the status of the system is equally important, in order to be able to draw some general conclusions and identify critical areas. This is, however, problematic, because the framework structure does not consider the whole system, but rather its single parts. For this reason, to identify key system components (third research question) is a difficult task since the framework does not provide any guidance with this regard. An additional obstacle to the identification of key system components is given by the difficulty of comparing the study with other countries; this aspect is discussed in section 4.3.

Nonetheless, looking at the single activity groups, a few conclusions can be drawn. The public authority appears to be a key actor in the innovation process, due to its ability to influence the setting of binding targets, the provision of financial incentives and the collaboration among stakeholders. Forerunning organisations are the main driver of biojet innovation, but a more active engagement of the large amount of actors looking favourably at the biojet transition is needed. These two components seem to be the most crucial factors determining the success of the innovation process; numerous interviewed stakeholders agree with this assertion.

What the framework is unable to provide is the full view of the innovation system. The issue of fragmentation has prevented to present in a uniform way the system status and features, hindering the identification of critical components. As stated in the previous section, the categorisation system helps provide a definition of the activities within the groups, but fails to detect the connections between different groups. A lack of comprehension of the relationships that make groups interact precludes having a better picture of the whole innovation system. The existence (or absence) of organisations or institutions and their related activities belonging to one group can have an impact on other organisations, institutions, and their related activities belonging to another group. Some positive feedback loops within the system are also identified.

Some of the relevant linkages between activity groups are the following:

a. Flexibility in the ASTM certification process (*Quality requirements*) ensures that new, more efficient technologies may be adopted in the future, encouraging the proliferation of research activities (*R&D results*);

b. An adequate provision of research funds (*Financing of the innovation process*) is a determinant for success of research activities (*R&D results*);
c. There is a strong correlation between the existence of market-based measures and targets on the one part (*New product markets*) and the achievement of early stage market competitiveness on the other (*Financing of the innovation process*);
d. Demand-side activities (*New product markets*, *Quality requirements*) are largely influenced by the presence or absence of laws and regulations (*Institutions*), and the administering bodies that oversee such laws (*Organisations*);
e. The presence or absence of some organisations, such as companies and public bodies, being at the forefront of the innovation process (*Organisations*) determines the extent to which national research projects are steered towards a specific area of interest (*R&D results*);
f. Advocacy activities (*New product markets*) are influenced by actors (*Organisations*), relationships among actors (*Networking*), and embedded norms (*Institutions*);
g. In turn, effective advocacy has an impact on legislation (*Institutions*), initial capital raising, early stage market competitiveness (*Financing of the innovation process*) and direction of research (*R&D results*);
h. Actors (*Organisations*) and the relationships among them (*Networking*) are difficult to separate, especially when it comes to interest groups.

This list does not intend to be full-inclusive, but it is rather meant to point out that many system features may have been neglected. This consideration indicates that, although the SI framework provides a solid basis for analysis of system components, the overall system is more than the sum of its parts.

4.3 Additional comments

Besides the discussion of results, the considerations about the framework suitability and the existence of connections between system categories, a few supplementary observations can be made.

Firstly, the fact that the SI framework has not been widely used with practical purposes and that aviation biofuels technology is at an early deployment phase worldwide leaves little room for comparison between the study findings and other research. Specifically, it is not possible to confront the Swedish biojet innovation system with aviation biofuel development in other countries. A number of studies investigated national-level feasibility of biojet deployment, but using different approaches and not analysing the innovation in a systemic perspective. In order to increase the significance of the study, the same method should be applied to other national systems of innovation. This process is facilitated by the fact that the study has a high degree of replicability.

As introduced in the previous section, the inability of comparing this research with other studies makes it difficult to pinpoint what are the key components that determine the success of the system, whether any drivers and barriers are peculiar of the Swedish context, and ultimately, whether Sweden, in a global perspective, is a suitable environment for the biojet innovation process. Further research is needed to give an answer to these matters.

A Swedish perspective allows to describe in detail key national actors and institutions, but in order to have a better understanding of certain system dynamics the analysis could have been incorporated on a larger scale. The decision to analyse the innovation system on a national perspective is aligned with the SI approach, and is relatively easy to apply. For the biojet innovation system, however, a scope on the Scandinavian region might have been appropriate, due to the strong connections between the actors in the area and the objective of NISA to promote the development of biojet in the Nordic. It could be argued that a global focus would have also been suitable for the study of biojet, since it would have allowed to better understand the complex dynamics characterising the aviation industry. For example, this study largely neglected the role of aircraft manufacturers (Airbus, Boeing) as a driver of technological change. Nonetheless, the aim of this research was to examine the innovation process in the Swedish area, thereby it appears appropriate to set the scope at the national level. Since study boundaries had to be defined, it has not been possible to give the full picture of actors, relationships, drivers and barriers that exist supranationally.

A final consideration regards the appropriateness of data collection methods. To investigate contextual aspects such as organisations' actions, perspectives, drivers and challenges it has been necessary to resort to grey literature published by business firms and interviews with company representatives. These sources of data are not absent of bias and may include subjective description of facts and opinions, as well as inaccuracies. The author acknowledges this as a factor limiting the correctness of the study.

5 Conclusion

In order to improve its environmental performance, the Swedish aviation sector is starting a transition in the use of jet fuel, substituting conventional fossil fuel with sustainable biojet fuel. This process, however, is hampered by obstacles of various nature.

Based on this premise, the purpose of the study was to assess the status of the biojet innovation system in Sweden, identifying system constituents and their functions; to detect drivers and barriers for future development; and to understand which components are the most crucial for success. Through the analysis of seven key activity groups provided by the conceptual framework, it has been possible to address and, to a certain extent, give an answer to these queries.

Looking at R&D activities, it can be noted a triangular research collaboration between privates, public bodies and the academia. All these groups of actors are active in conducting research, and many initiatives are performed at the national level. However, the extent to which this research targets specifically the area of aviation biofuel is quite limited.

The presence of numerous self-imposed targets and official documents envisioning a roadmap for sustainable fuel transition is counterbalanced by the absence of any market-based measures or national and European binding targets. However, activities encouraging the implementation of measures and targets have been observed, and an ICAO emission market-based instrument regulating international aviation is planned to be established from 2020. The scarce government interest in aviation sustainability is recognised as a major barrier to biojet innovation and is addressed through lobbying activities performed by various stakeholders, though with limited results.

The ASTM certification includes standards defining conventional Jet A-1 fuel and synthetic Jet A-1 fuel. Three production processes are currently accepted for the production of synthetic fuel, but the certification scheme design entails that additional processes may be included in the future. Alternative processes are undergoing the certification procedure. In general, it can be argued that international recognition of synthetic fuels suitability is a driver for innovation, facilitating biojet diffusion. On the other hand, a lack of clarity with regard to biojet sustainability criteria is observed; an intense dialogue between stakeholders to provide more accurate definitions is taking place.

A large number of organisations can influence the innovation process. These organisations are present among the supply chain actors – producers, distributors and users – and outside the supply chain, comprising the Swedish government, national agencies, the EU, research bodies, interest groups. A small group of actors at the forefront are pushing the innovation process forward; activities performed by them are often the most crucial for the success of the innovation process. In a complementary fashion, many organisations are favourable to the development of biojet but participate passively to the innovation process. Among these lay potential key actors.

Connections among organisations are present at any level, facilitating dialogue. The most interesting initiatives are the result of collaborative projects among different types of stakeholders, ensuring the achievement of synergies. Public authorities are a part of these networking activities, though their collaboration could be more substantial.

Laws at the national, European and international level govern biojet technology and its diffusion. The existing legislative framework does not address some biojet-related issues such as sustainability criteria, and fails to provide assistance to development. A change in the legislation would require a long negotiation process. A number of embedded rules, norms and behaviours have been identified: the majority of them appear to facilitate the innovation process rather than hindering it.

The analysis indicated that the presence of issues regarding the act of raising initial capital for research projects and small SMEs can be overcome to a certain extent through the financing support provided by certain actors. A more problematic barrier for success is the difficulty for innovative biojet technology to reach market competitiveness and critical volumes of production in the early stage of its development. This issue causes uncertainty in the market, discouraging investors to finance biojet projects and therefore creating a vicious cycle. The price gap between conventional and renewable fuel is currently not addressed by the legislation. No incentives are in place at the moment, since tax exemptions are set for conventional biofuels and do not include biojet. Various financing mechanisms are being proposed but no agreement among stakeholders has been reached.

These considerations gave an answer to the first and the second research questions. Regarding the third research question, however, key elements determining the success of the innovation process proved to be difficult to pinpoint. Still, from the analysis few components can be identified. It can be argued that national authorities can play a major role in the setting of legislation regarding targets, market-based measures and financial incentives. This aspect has to be addressed by policymakers, who are the actors that can have an impact on such authorities. In addition, many organisations expressed interest towards biojet technology. If that interest became proactive involvement in biojet-related activities, these organisations would have a strong impact on the innovation process. It is the task of industry stakeholders to increase the engagement of these actors.

Overall, it is problematic to assess which existing and missing components are fundamental for the success of the innovation process. In order to get a better understanding on this subject, a comparative analysis with similar national studies is needed. The study has, at the theoretical level, a high degree of replicability. Further research investigating the biojet innovation process in other national settings would be not only valuable *per se*, but would also increase the significance of this study, allowing to compare strengths, barriers and features of different countries and to identify which elements are the most crucial for success.

In addition, future research should address the data gaps that have been identified in the study. For instance, this research project has not performed a thorough analysis of cultural norms and behaviours characterising the interactions among the actors. These aspect belong to the social and behavioural sciences and should be further addressed. Moreover, information retrieved in personal communications and interviews should be scrutinised and verified by a more comprehensive analysis of activities performed by organisations. Another topic that merits deeper analysis the intrinsic issue of aviation as a sustainable form of domestic transport. Broad system studies should examine the extent to which aviation could be substituted by more environmentally-friendly means of transportation. Lastly, financial measures ensuring early stage market competitiveness of biojet are currently being discussed among stakeholders, but the debate lacks academic research on the suitability of many of these measures. Thereby, further studies on financial mechanisms to spur biojet diffusion should be conducted.

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Appendix I: Interview list

Arne Karyd, independent aviation consultant, June 13, 2014.

f3: Ingrid Nyström, Representative, June 12, 2014.

Karlstad Airport: Peter Landmark, Representative, August 8, 2014.

Malmö Aviation: Ann-Sofie Hörlin, Representative, August 11, 2014.

Neste Oil: Fredrik Tornqvist, Representative, June 16, 2014.

Nordic Initiative for Sustainable Aviation (NISA): Martin Porsgård, Director, June 12, 2014.

Paper Province: Per Bjurbom, President, August 26, 2014.

Lund University: Pål Börjesson, Researcher at Lunds Tekniska Högskola, June 18, 2014.

SAS: Lars Andersen Resare, Representative, September 2, 2014.

SkyNRG: Misha Valk, Representative, June 12, 2014.

Statoil Aviation: Thorbjörn Larsson, Representative, June 9, 2014.

Swedish Energy Agency (STEM)(a): Kristina Holmgren, Representative, June 19, 2014.

Swedish Energy Agency (STEM)(b): Alice Kempe, Representative, June 26, 2014.

Swedish Bioenergy Association (Svebio): Lena Bruce, Representative, June 9, 2014.

Svenskt Flyg: Anna Wilson, Representative, September 1, 2014.

Swedavia: Christina Sares, Environmental Advisor, August 27 and September 8, 2014.

Swedish Transport Agency (TS): Annika Lindell, Representative, and Therese Sjöberg, Senior Environmental Advisor, June 10, 2014.

Vinnova: Marit Werner, Representative, August 22 and 26, 2014.