Becoming green while flying blue

A graduation project for the MSc in Management of Technology

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by

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Preface

In the last few months, I have been busy delivering this thesis. It was a very special project for me as I had already finalised another Master of Science in Biomedical Technology & Physics. The topic of this thesis was very refreshing and exciting for me as it was completely different compared to my study background. Besides my project, I have learned much about the aviation industry and its complexity. I was positioned at Fleet Services, which maintains and manages the fleet of KLM. I have worked with many passionate people willing to teach me all the ins and outs of a plane. I saw all the backstage action of maintaining a fleet, took a first glance at the new premium economy class, and ultimately had the opportunity to be on board a flight simulator during pilot training. It was truly a unique final period of my student career.

As it was not my first thesis, I received a lot of confidence from all my supervisors and was allowed to be my project manager. I appreciate the freedom and trust given to orchestrating the final stage of my career as a student. For that, I want to thank all of my supervisors. And with that sentence, I officially mark the end of my Master of Science in Management of Technology.

Executive summary

The global debate on the climate crisis is more present than ever. Reducing carbon emissions in all industries is one of the major goals to avoid further major climate consequences. The energy-related sector produced 36.3 Gt of carbon dioxide (CO_2). This number includes all emissions of combustion of fossil fuels in industry process and transport (IEA, 2021). Of the 36.3 Gt CO_2, the aviation industry produced around 2,1% (Ge et al., 2022). Although the entire energy sector, including the aviation industry, experienced a small decrease in emissions from COVID-19, emissions again rose in 2022 (Ge et al., 2022). Hydrogen, battery-electric, and SAF are the main topic of debate to decrease aviation-related CO_2 emission,

In the literature, many papers were found on the technical opportunities and barriers of all three technologies. Additionally, economic studies were found on the transition towards the three technologies. However, the transition from an innovation system perspective is little discussed. This study wanted to explore the transition from a technology innovation system (TIS) perspective, including the role of KLM in the transition. The following research question was established: *What are the opportunities and barriers to deploying sustainable aviation technologies?*. The aim was to identify barriers and opportunities from a macro- and micro-level perspective to understand what role KLM could play in the transition towards sustainable aviation technologies. The research used an exploratory qualitative approach.

Several theoretical models were considered to construct a conceptual framework. The final conceptual framework used two theoretical foundations, one for the macro-level and one for the micro-level. The foundation for the macro-level analysis was found in the seven functions of a TIS by Hekkert et al. (2007). The seven functions are *entrepreneurial activities, guidance of search, knowledge creation, expectations, allocation of resources, legitimise/lobby* and *market formation*. The seven functions are interrelated and describe the performance of a TIS with three motors of an innovation system. One of the functions, *entrepreneurial activities*, was explored in depth using the micro-perspective as a case study at KLM. For the micro perspective, this study used strategic management of innovation theories by Schilling (2019).

This study used exploratory qualitative research to identify barriers and opportunities within the theories of Hekkert et al. (2007) and Schilling (2019), in the form of semi-structured interviews. Eight interviews were conducted with industry experts to explore the state of the seven functions and identify opportunities and barriers. In the case study, three KLM (program) managers were interviewed to explore their entrepreneurial activities and how KLM organises innovation. Additionally, the macro perspective results were discussed with one of the KLM managers to discuss the alignment with the activities of KLM.

The results of this study showed that the technology innovation system is not performing optimally. Most barriers were recognised in the model's legitimisation and market formation functions. This is mainly applicable to hydrogen and battery-electric. The reason was the early stage of these technologies. Legislation for all three technologies, mainly hydrogen and battery-electric, is not present yet. This factor resulted in the obstruction of market formation due to the high safety standards in the aviation industry. Furthermore, financial and legislative incentives were missing to stimulate the entrepreneurial activities of actors within the TIS. A second barrier was the need for appropriate test environments to test new technologies. Another barrier was the reluctance of incumbents such as KLM. This reluctance is explained by the early stage of hydrogen and battery-electric aviation, which entails risk and, therefore, reputation damage.

Opportunities found were in the guidance of search and knowledge creation. As the need for sustainable solutions is significant, the focus of the search is guided by the global demand for sustainable solutions. Results showed that knowledge institutions are occupied with main hydrogen and battery-electric solutions for aviation. Results showed regional differences in the preference for these technologies. This finding was also in line with the expectations of the industry experts. The unanimous expectation for future passenger aviation consisted of a symbiosis between all three technologies: battery-electric would fulfil ultra-short distances, hydrogen medium-long hauls, and SAF for long hauls. However, significant technological advancements are required for both hydrogen and batteries. Therefore, the knowledge creation function significantly impacts the TIS of sustainable aviation.

The micro-level results showed that the entrepreneurial activities of KLM for sustainable aviation are currently in an exploratory phase. A program manager for zero-emission aviation explored the field and mapped parties and activities focusing on hydrogen and battery-electric initiatives. SAF was considered less part of the program as it is already used in daily operations. Barriers within KLM were found in the priority of disruptive innovation, standardised daily operations that result in the need for operational efficiency, and the risk of reputation damage.
The interviews revealed opportunities to map internal and external innovation projects, formulate an innovation strategy, and seek collaboration with start-ups and new actors. Opportunities related to the macro-level for KLM included actively lobbying and taking the lead to communicate technical and project successes and barriers and collaborating with policymakers to introduce legislative incentives, such as tax benefits, for fleet renewal.

In conclusion, this study revealed that the TIS for sustainable aviation technologies is currently active. However, the TIS is not performing optimally as main barriers emerge for the function legitimisation and lobby, obstructing the transition towards a sustainable aviation future. KLM could take a leading role in overcoming these barriers by using its reputation and profound industry knowledge. For this, it is important that KLM prioritises innovation and use its will to pioneer in the transition. A long road lies ahead for the industry to become green due to the complexity of the actor network and the technical challenges. Nevertheless, given the technological advancements, it is expected that the first battery-electric flights will emerge in this decade, marking the start of a sustainable aviation industry.

Recommendations were made for policymakers, KLM, and science. The main recommendation for policymakers is to install legislative incentives for entrepreneurial activities and stimulate the market in the future. Furthermore, aerospace should be made available to test battery-electric and hydrogen technologies.
Recommendations for KLM are to prioritise innovation by reorganising innovation teams in the organisation. Autonomous teams should be installed that are separated from the core business to explore new business models and the impact of new technologies on the existing model.
Future research should investigate the role of sustainability on the TIS. Also, during the interviews it came forward that the relation between *entrepreneurial activities* and *knowledge creation* is bilateral rather than unilateral as presented in the TIS model. Research should further investigate the impact of the bilateral relation on the model.

Contents

List of Abbreviations

CH_4 methane

CO_2 carbon dioxide

CORSIA carbon offsetting and reduction scheme for international aviation

GHG greenhouse gases

ICAO International Civil Aviation Organization

KLM Royal Dutch Airline

LH_2 liquid hydrogen

MLP multi-level perspective

N_2O nitro oxide

SAF sustainable aviation fuel

ST socio-technical

TIS technology innovation system

VTOL vertical take off and landing

1 Introduction

The aviation industry is one of the significant activities for the world economy, but also one of the most energy-demanding activities (D. Lee et al., 2021). Since 1960, aviation emission has increased by a factor of 6.8 in 2018 for passenger flights (D. Lee et al., 2021). Although emission numbers have dropped due to the decrease in passenger flights during COVID-19, it is expected that the number of flights before COVID will triple in 2050 (Gössling & Humpe, 2020). As a result, emission numbers of the aviation industry will further increase, conflicting with global climate goals (Larsson et al., 2019).

New technologies for fuel and propulsion systems are the key to discontinuing the increasing emission problems of the aviation industry. In the last decades, several alternatives are emerging in the aviation industry. The overarching fields of emerging technologies are hydrogen, battery-electric, and sustainable aviation fuel (SAF) (Walker, 2020; Zoccatelli & Nascimbeni, 2021). The carbon footprint of these differs. The production method of hydrogen and electricity determines the footprint of both technologies. Electricity or other resources must come from renewable sources, such as the wind or the sun, for a neutral footprint. SAF can reduce the carbon footprint but cannot reduce the carbon footprint to zero. SAF can be made bio-based from different resources such as sugar and starch crops, biomass, (used) vegetable oil, animal fats, or a combination of synthetically with hydrogen and CO_2 (power to liquid). Because SAF is made from resources in which CO_2 is captured, SAF can reduce the carbon emission up to 80%, but does not reduce the emission to zero (IATA, 2019). Although SAF cannot reduce the emission to zero, it offers a "*drop-in*" solution, which means that SAF retrofits within existing aircraft and the current logistics and infrastructure of modern aviation (Siew et al., 2021). Net-zero technologies, hydrogen and battery-electric, however, come with new challenges and require changes in the current aviation system.

The transition from the current technology standard, jet fuel propulsion, towards net-zero propulsion can be seen as disruptive. Net-zero technologies are discontinuous as they fulfil a similar need: air transport. The knowledge base, however, differs for these technologies (Schilling, 2019). The current market in which the standard technology operates consist of multiple actors and legislation and depend on deeply embedded rules and social structures, also known as a socio-technical (ST) regime (Geels, 2002). Incremental change and standard technology trajectories characterise the ST-regime. Net-zero technologies will most probably disrupt the system when pressure from society increases and disruptive technologies make jet fuel technologies obsolete (Geels, 2002).

New technologies mostly emerge in niche environments (Geels, 2002). In contrast to the ST-regime, networks are fluid and can still be changed, and actors come and go in these environments. Bergek et al. (2008) describes this dynamic as the TIS. The system comprises actors, networks, and institutes. When the dynamics in this system solidify, these niches could break out to the ST-regime (Bergek et al., 2008; Geels, 2002). To understand the dynamics and how the TIS is performing, Hekkert et al. (2007) introduced seven innovation system functions. These seven functions introduced a method to assess the innovation system. Moreover, the theory of Bergek et al. (2008) and Hekkert et al. (2007) can describe the interaction between different technologies, as is the case for sustainable aviation.

1.1. Research problem

Transitioning from the current aviation system to a sustainable system comes with many challenges and is complex. A preliminary search concluded that technical, political, and economic challenges for sustainable aviation are broadly discussed in literature (Cecere et al., 2014; Kulanovic & Nordensvärd, 2021; Sripad et al., 2021; Walker, 2020; Zoccatelli & Nascimbeni, 2021). At the same time, a deep understanding of the transition barriers and opportunities of the innovation system is little described in literature.

Little to no research was found concerning a technology innovation system for the sustainable transition of the aviation industry. In the preliminary search, J. Lee and Mo (2011) described the technology innovation system for the aviation industry but again focused on the technical feasibility and pathways. However, J. Lee and Mo (2011) does not discuss the performance of the innovation system and does not include a micro perspective of the innovation system. Besides a description of the innovation system, it would be interesting to research the performance and to seek what factors would influence the performance. Therefore, investigating transition challenges of the innovation system from a macro and micro perspective was considered worth investigating.

1.2. Research objective

This research will investigate the performance of the current technology innovation system of sustainable aviation technologies and the current innovation activities of an airline regarding sustainable aviation. It was chosen to include a macro- and micro-perspective to better understand what role KLM could play in the transition towards sustainable aviation. In order to do so, this study wants to obtain an overview of the current functions of the innovation system for sustainable aviation Hekkert et al. (2007) and create an overview how KLM organises innovation and what activities are currently active regarding sustainable aviation. The framework of Hekkert et al. (2007) offers several functions to describe the performance of an innovation system. This study used the functions to investigate and identify barriers and opportunities in the innovation system and what role KLM could play in the innovation system.

1.3. Research questions

Based on the previous paragraphs, this research formulated the main question:

> *What are the opportunities and barriers to deploying sustainable aviation technologies?*

This question was from the perspective of the TIS, the functions, and the focus of the microanalysis at Royal Dutch Airline (KLM). The following sub-questions were formulated:

SQ1: What is the current state of sustainable technologies in aviation?

SQ2: What are the potential transition pathways of sustainable technologies in aviation?

SQ3: What is the state of functions in the sustainable aviation innovation system, and are the system's motors running?

SQ4: What are the current innovation activities in KLM, and how is innovation organised?

SQ5: How do the current innovation activities align with the functions of the innovation system?

SQ6: What can KLM learn from other industries that were disrupted by emerging technologies?

SQ7: What can actors improve to enhance the functioning of the sustainable aviation innovation system?

1.4. Scope

Based on the contextual background of Chapter 2, this research will focus on three technological fields for net-zero aviation solutions: hydrogen, battery-electric, and SAF. Technological advancements for these solutions and regulation for aviation are mainly internationally orientated. Limiting the scope to the Netherlands would limit the findings of this study. Therefore, no limitations were made concerning regional boundaries. Nevertheless, this study focused on the perspectives of solely Dutch participants as this thesis is performed for the TU Delft with a case study at KLM, which situates in the Netherlands.

Advancements in battery-electric aviation also introduced new aircraft types with capabilities such as vertical take off and landing (VTOL) (Bauen et al., 2020). VTOL could open up new methods of air transport and markets for net-zero aviation. This study did not consider new flight methods; hence, this research will focus exclusively on using hydrogen, batteries, and SAF in the commercial aviation industry.

This thesis focused on projects related to flying with sustainable technologies. Ground operations, such as cars and passenger transport at an airport, were ignored. Nevertheless, during the case study at KLM for innovation, all innovations were included to see the overall innovation strategy.

1.5. Thesis structure

This thesis is divided into seven chapters. The next chapter, chapter 2, will give the context of the different technologies considered for sustainable aviation. Chapter 2 was based on a literature search and aimed to better understand the technologies considered in this research.

Chapter 3 will present the theoretical considerations of this thesis. The chapter will elaborate on the choices made. Furthermore, the chapter will discuss the theoretical background of organising innovation. The theoretical background on organising for innovation was used to reflect on the microanalysis within KLM and hold close ties to the curriculum of the MSc Management of Technology study, for which this graduation project was performed. The chapter ends with the conceptual framework of this study.

Chapter 4 will present the research method. Although the choices and considerations were part of the method of this study, I chose to discuss these considerations before the method chapter because the data collection and analysis were based on the conceptual framework. To improve the readability of this thesis, I decided first to discuss and present the conceptual framework to give the reader upfront knowledge to understand the method.

Chapter 5 presents the results obtained during the study. The chapter separated the results for the macro and micro analysis. The interpretations of the results will be discussed in chapter 6. The interpretation chapter will reflect the findings on the theoretical background and the conceptual framework of this study. Furthermore, the chapter is considered to be the basis for identifying the barriers and opportunities.

This thesis will end with chapter 7. This chapter includes the conclusion, reflection on the research in the form of limitations, and will finalise with recommendations. Recommendations are given for policy, the industry, and future scientific research.

2

Contextual background

This chapter will give a more in-depth view of the context in which this thesis was done. It will elaborate on global climate change and promising net zero propulsion technologies. Lastly, this chapter discusses the role of KLM.

2.1. Global climate change

Climate change is one of the most significant global crises of the modern world. Since 1800, the average temperature has increased by 1,1 degree Celsius. The temperature rise resulted in the five warmest years on record (UN, 2021; WMO, 2020). Without any discontinuity, scientists expect that the temperature rise will increase between $2°C$ and $4°C$ at the end of this century (Berrang-Ford et al., 2011). Consequently, the trend for sea-level rise is accelerating, Antarctic mass is decreasing, and hurricane seasons are becoming more frequent and more prolonged (WMO, 2020).

The cause of global warming is the rising emission of greenhouse gases (GHG). GHG comprise a group of gases that retain heat from the sun. The three major gases that cause global warming are CO_2, methane (CH_4), and nitro oxide (N_2O). Human activity causes most of the emission of these gases (Stern & Kaufmann, 2014). Since the industrial revolution in 1750, CO_2, CH_4, and N_2O concentrations have increased by 148%, 260%, and 123% respectively (WMO, 2020).

Although all three GHG increase the effect of global warming, CO_2 has the most severe effect (D. Lee et al., 2021). Last year, the energy-related, such as combustion and industry processes, CO_2 emission grew to 36.3 Gt (IEA, 2021). Of the 36.3 Gt CO_2, the aviation industry produced around 2,1% (Ge et al., 2022). Although the total energy sector, including the aviation industry, experienced a small decrease in emissions from COVID-19, emissions again rose in 2022 (Ge et al., 2022).

One of the solutions to reduce aviation emissions is reducing the number of flights and passengers (Obbink, 2022). This solution has one major problem: only a small percentage of the world's population uses air transport, namely, the wealthiest people. 50% of all aviation emission is caused by 1% of the world population (Obbink, 2022). Because multiple nations have become wealthier, such as China and India, it is not likely that reducing passenger numbers is the solution to reduce emissions (Obbink, 2022).

2.2. Climate goals

One hundred ninety-six countries signed the Paris climate agreement in 2015 to avoid substantial consequences for the climate (UNFCCC, 2015). In the agreement, all countries agreed to limit global warming to $2°C$ compared to pre-industrial levels. The peak of GHG emissions as soon as possible to reach this goal. All countries presented their nationally determined contributions to reduce their GHG emission (UNFCCC, 2015). For instance, the Dutch government aims to reduce their GHG emissions by 49%, compared to 1990, by 2030 and become climate neutral in 2050 (Ministry of Economic Affairs and Climate, 2019). In order to do this, the government set commitments to five sector platforms: built environment, mobility, industry, agriculture and land use, and electricity (Ministry of Economic Affairs and Climate, 2019).

2.2.1. Climate goals for passenger aviation

The Paris agreement states that the International Civil Aviation Organization (ICAO) is responsible for reducing the climate impact of the overall aviation industry (Ministry of Economic Affairs and Climate, 2019). The ICAO initiated the carbon offsetting and reduction scheme for international aviation (CORSIA) to prevent carbon emissions from rising above the level of 2021. Although the set goal, no specific strategy or commitments were set as individual states experience different circumstances and capabilities. Therefore, states must contribute according to their capabilities and methods (ICAO, 2022).

For example, the state action plan of the Netherlands, published on the website of the ICAO, set the following goals for international aviation. First, the CO_2 emission should be less or equal to the total emission in 2005. Secondly, reduce the domestic CO_2 levels by 50% in 2050 compared to levels of 2005. Lastly, net-zero aviation should be reached in the year 2070. These goals apply to the flights (ICAO, 2022; Ministry of Infrastructure and Water Management, 2022).
For domestic aviation, the government set two additional targets. First, ground services should be net-zero in 2030. Secondly, domestic aviation should become net-zero in 2050 (Ministry of Infrastructure and Water Management, 2022). This goal states that terminal buildings, passenger transport at the airport, such as buses and, taxis, and tugs should be zero-emission.

2.3. Clean propulsion technologies

The previous section discussed the climate impact of civil aviation. Worldwide, ambitions are to reduce this impact and eventually become net zero. The will to do so becomes evident in the many entrepreneurial activities and projects. Figure 2.1 gives an overview of published projects with their timeline, core technology, passenger numbers, and range.

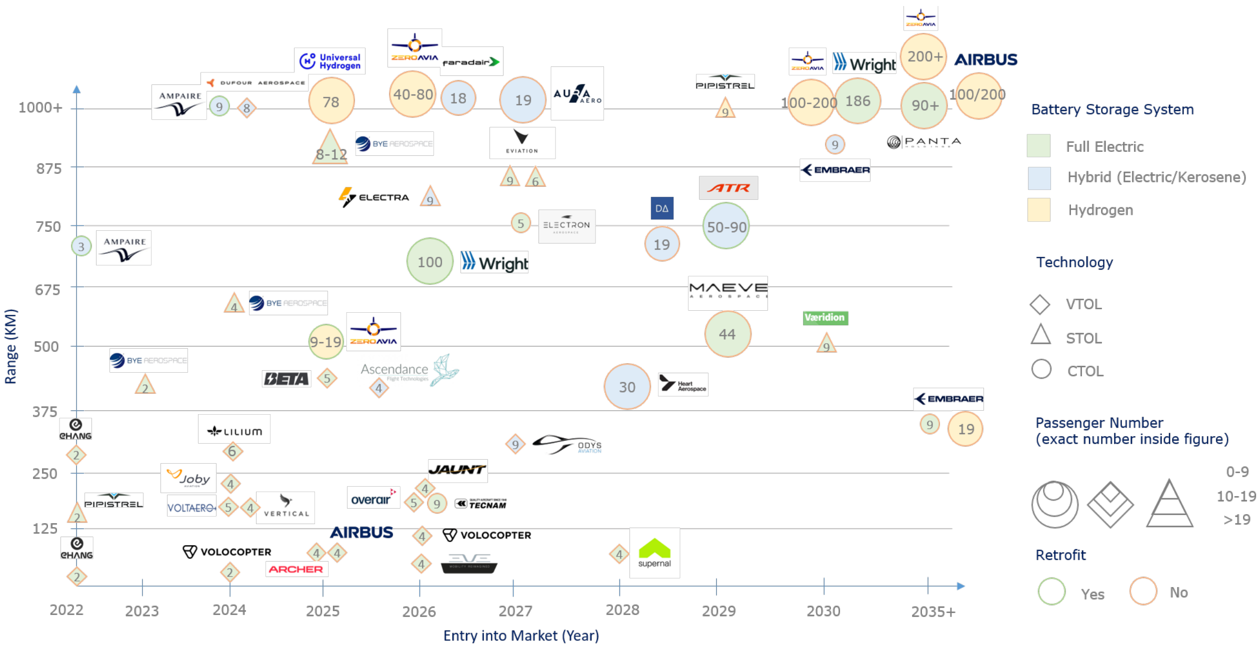

Figure 2.1: Overview of current projects for net-zero aviation with their aimed technology, passenger numbers, range, and schedule (Ullrich, 2023).

In order to reach the goal of becoming net zero, propulsion technologies, ground services, and onboard electronics require advancements. Three energy vectors for propulsion dominate the current debate for carbon-reducing and net zero technologies: SAF, hydrogen, and battery electric (Zoccatelli & Nascimbeni, 2021). Figure 2.2 shows an overview of all energy vectors, the needed resources, and how the vectors are used to propel the aircraft.

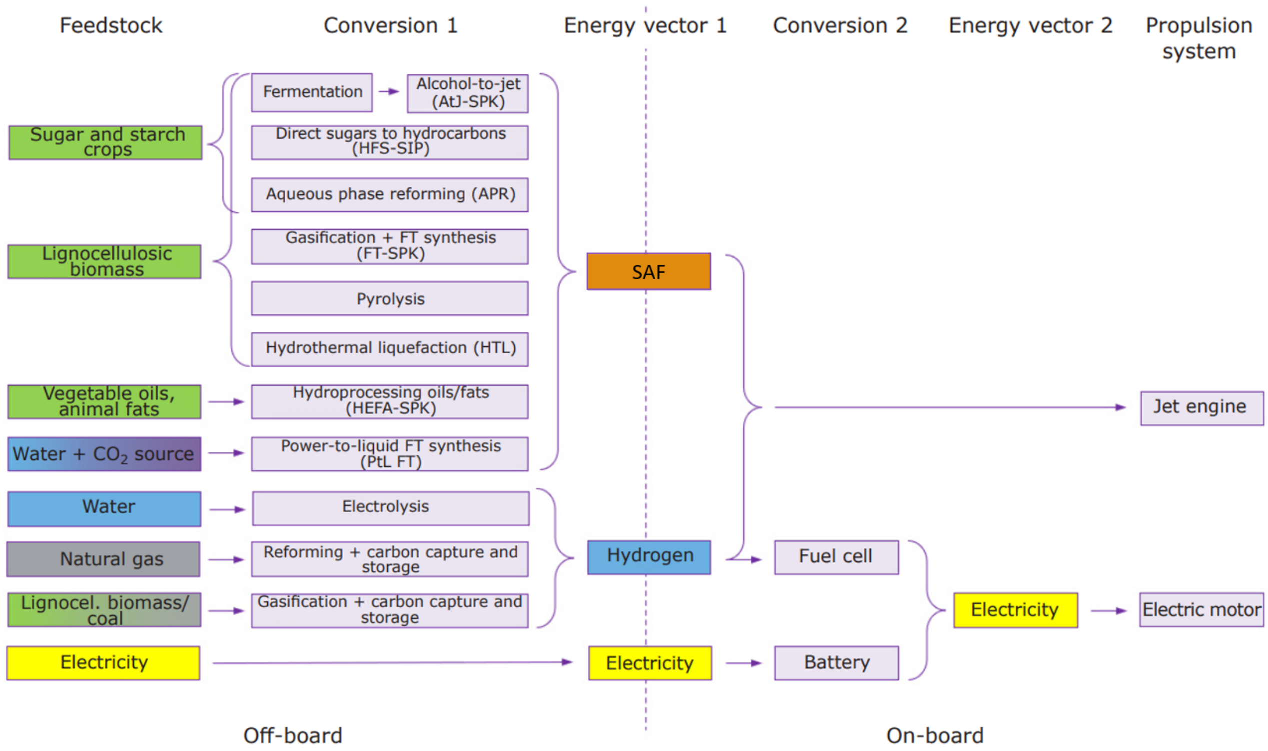

Figure 2.2: Overview of all available techniques for new energy vectors (Bauen et al., 2020). The three energy vectors displayed are SAF (orange), hydrogen (blue), and electricity (yellow).

2.3.1. Sustainable aviation fuel

SAF is a renewable and fungible fuel that has the potential to replace kerosene to reduce emissions. SAF can reduce carbon dioxide emission by up to 80% (IATA, 2019). Not only has SAF the potential to reduce emissions, it also reduces contrails and increases engine efficiencies (Vardon et al., 2022). In the current state of the technology, SAF can only be used blended with traditional fuels (Martinez-Valencia et al., 2021). SAF refers to multiple types of fuel. SAF can be made from different resources and has multiple forms. There are two types of production methods: bio-based and synthetic (IATA, 2019; Martinez-Valencia et al., 2021; Vardon et al., 2022).

There are three profound production techniques in the market of SAF. The first technique is oleo-chemical. In this production method, physio-chemical pathways convert fatty acids. The second method is biochemical, in which microorganisms process carbohydrate feedstock to form an intermediate product. Feedstock can refer to several types of raw materials, such as soybean oil. The last certified method for SAF production is thermo-chemical in which macro-molecules from solid biomass are deconstructed (Martinez-Valencia et al., 2021).
Besides the three certified techniques mentioned above, additional techniques have demonstrated their readiness but still need to be certified, such as aqueous phase reforming, pyrolysis-Fischer Tropsch, and hydrothermal liquefaction. The difference between the certified methods is that these techniques require additional hydrogen to enrich the fuel for usage. Therefore, these techniques require co-innovation with hydrogen production (Martinez-Valencia et al., 2021).

The main benefit of SAF liquids, compared to batteries and hydrogen, is that it is a ”drop-in” solution, which means that SAF fuels existing engines without modifications (IATA, 2019; Siew et al., 2021). Because SAF can be used immediately, this technology is a vital pillar of the ICAO to reduce GHG emissions. However, the biggest obstacle to the wide adaption of SAF is the price and the availability of resources.

2.3.2. Hydrogen

The use of hydrogen is not new. The exploration for hydrogen already started before the second world war (Benson et al., 2019). Hydrogen is a preferred fuel as it has a high combustion heat, meaning that hydrogen combustion delivers a lot of energy (Benson et al., 2019). Hydrogen has an energy that is 2,5 times bigger than kerosene (Baroutaji et al., 2019). The main problem of using hydrogen as a fuel is that hydrogen has a low volumetric density, four times bigger than kerosene (Sharpe et al., 2015). Cecere et al. (2014) states that hydrogen flying is still more weight efficient as propulsion systems are more lightweight than traditional propulsion systems.

Because hydrogen contains much energy, hydrogen is the standard fuel for aerospace projects and spacecraft (Benson et al., 2019). For hydrogen to become viable in the passenger aviation industry, a compressed or cooled storage technology to liquidise the hydrogen liquid hydrogen (LH_2). Without liquidation, the energy density is too low (Baroutaji et al., 2019; Bauen et al., 2020). The current tanks for kerosene, placed in the wings, are not suitable for these techniques (Baroutaji et al., 2019). Figure 2.3 shows possible configurations of hydrogen storage.

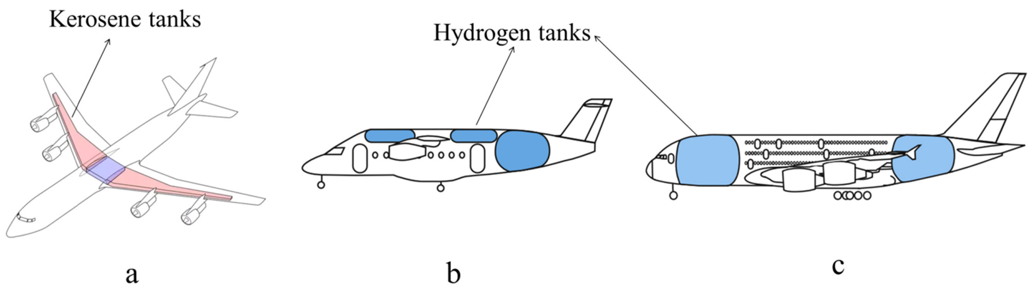

Figure 2.3: Possible tank placements for LH_2 (Baroutaji et al., 2019)

Due to the low temperature and high pressure, using LH_2 is not without danger. Hazards include cryogenic burns, liquid-to-gas expansion, and flammability. Therefore, the use of LH_2 requires strict regulations (Benson et al., 2019). Despite this, several airports (Heathrow, Berlin, LA) have completed projects for hydrogen fuelling. Moreover, several projects in the USA and Germany accomplished successful flights with hydrogen fuel cells. The test in Germany flew with 10 kg of hydrogen, but with a fully loaded tank, the four-seated aircraft could fly 1000km with a speed of 145 km/h (Bauen et al., 2020). A recently published project is a commercial 19-seated hydrogen plane of ZeroAvia that has close collaborations with Rotterdam Airport. Their mission is to fly the first plane in 2024 from Rotterdam to London (Kaminski-Morrow, 2021).

While significant technological, safety, and regulatory challenges must be overcome, hydrogen has a great potential to reduce GHG as the only by-products of hydrogen combustion are water vapour and nitrogen oxides (Baroutaji et al., 2019). Both products are still considered as GHG, but compared to kerosene, the use of hydrogen would reduce GHG severely (Bicer & Dincer, 2017).

2.3.3. Battery-electric

The electrification of planes started with auxiliary systems as these were more lightweight compared to mechanical units (Walker, 2020). Although battery-electric planes have the potential to reduce fuel and emission, technical problems occur considering the energy density of batteries (Walker, 2020). For that reason, current battery flights are mainly for recreational purposes, according to Walker2020.

Two configurations are considered for commercial flights: hybrid and full electric (Walker, 2020). The battery package and the turbofan are configured in parallel or in series in a hybrid configuration. This configuration allows the battery pack to support the traditional combustion engine. With the support, fuel consumption can be optimised (ICAO, 2019).

Full battery-electric propulsion, with the batteries as its single energy source, has many benefits in terms of emission and noise reduction. The potential of these planes is recognised. Still, batteries' energy density and weight remain the most prominent obstacle (Walker, 2020). For the same reason, only short-haul flights are possible. Currently, only a two-seated Pipistrel exist that can fly for 40 minutes (Pipistrel, 2022).

Apart from technical difficulties, battery safety concerns should also be considered a significant factor for commercial implementation (Sripad et al., 2021). Battery hazards fall into two categories, exothermic heat events and loss of power (Sripad et al., 2021). Safety measures should be considered, especially because batteries will be exposed to extreme temperature and pressure conditions. In this view, the degradation of battery packets would also play a significant role (Sripad et al., 2021)

2.4. The role of KLM

This study aims to understand what role a major airline operator could play in accelerating sustainable aviation. Therefore, conducting this study at one of the major airlines in Europe will contribute to the value of this thesis. KLM has more than a century of experience in the airline industry. The organisation has a profound knowledge of passenger transportation, cargo transportation, engineering and maintenance, and all other aspects of the airline industry. Moreover, KLM can offer an extensive network which can be used to find interviews and other sources of information.

Besides the extensive knowledge and network, KLM also publicly announced that they want to be one of the front-runner companies to become sustainable. Their mission is to become sustainable and invest in new initiatives. Therefore, KLM has much internal knowledge of the current field of innovation and the players in the market.

3

Conceptual framework

This study aims to explore the barriers and opportunities for the transition towards carbon-neutral aviation with the perspective of KLM. To accomplish this aim, the objective is to better understand external developments of sustainable aviation and the internal strategy for innovation. To conceptualise the objective, the theories learned in the curriculum of the master of science Management of Technology were considered. A combination of theories is presented that served as building blocks for the conceptual framework. For the external innovation development, two theories were considered for sustainable innovation and the transition of the aviation industry: the multi-level perspective (MLP) and the TIS. These models share similar conceptual grounds and take into account path dependency, non-linearity, and lock-in phenomena (Markard & Truffer, 2008). Both frameworks provide a deeper understanding of the transition of radical innovations and complement each other (Markard & Truffer, 2008). These frameworks were chosen as characteristics of the frameworks are seen in aviation industry and the emerging carbon-neutral technologies. The aviation industry conceives of multiple stakeholders from different entities such as government, institutions, airlines, and manufacturers. Because the innovation of these new technologies involve the interaction of multiple stakeholders and networks, the MLP and TIS were assumed to be suitable. To better understand the interaction between the emerging technologies and the current aviation regime, both frameworks were considered, as well as the integrated view of both theoretical frameworks.

For the internal analysis the book Strategic Management of Technological Innovation of Schilling (2019) was used. The book offers three parts: *Industry dynamics of innovation*, *Formulating Technological Innovation Strategy*, and *Implementing Technological Innovation system*. To reflect on the current strategy of an incumbent airline, KLM for this case study, the last chapter will be considered. The current strategy and organisation of KLM will be reviewed based on the theory offered in part three.
The following sections will further elaborate on both frameworks for the external innovation analysis and the integrated view of the frameworks. After that, the theories mentioned in part three of Schilling (2019) will be presented.

3.1. Multi-level perspective

The MLP was first described by Geels (2002). The framework describes technological transition as an interactive process between the micro-, meso-, and macro-level (Markard & Truffer, 2008). Geels (2002) refers to these levels as the niche-, socio-technical regime-, and landscape-level, Figure 3.1.
The meso-level, *socio-technical regime*, consist of current dominant regime. It refers to the current dominant industry and its technology in the market. For aviation this would be centred around the traditional kerosene propulsion airplanes. The theory divides the ST-regime in seven sub-dimensions that shape the regime around the technology, Figure 3.1. For the aviation industry, this level can be described by incumbent airlines, kerosene propulsion technologies, kerosene supply chains, and incumbent aircraft builders, such as Boeing and Airbus. Figure 3.2 gives an overview of most prominent stakeholders in the ST-regime for aviation. Innovation and progression in the ST-regime are mostly incremental rather than radical. Nevertheless, as this level consists of multiple dimensions and co-evolves over time, tensions may appear between different dimensions, which opens up opportunities for more radical change (Geels, 2002).

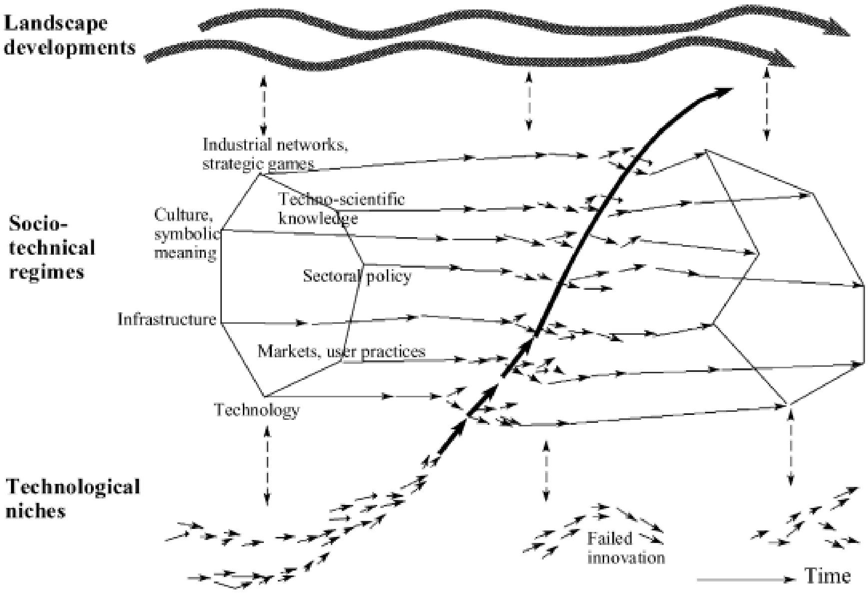

Figure 3.1: Multi-level perspective on technological transition (Geels, 2002).

The meso-level, or ST-regime, has a interaction with the the macro-level, *landscape*. The influence of the landscape on the ST-regime consists of trends in the societal and political world. These trends are formed and vary from decade to decade. For aviation, current trends that are seen are sustainability and climate impact, as described in the previous chapter. The interaction between the ST-regime and landscape are bilateral so that the ST-regime also forms and shaped trends in the landscape. Regime actors most often lobby in politics to give shape to trends that are commercially attractive for the regime (Geels, 2002).

The last and smallest level described in the framework by Geels (2002) is the *niche*-level. Niches do not play according to the rules of the ST-regime. Innovations and progress on this level are characterised by their radical nature. This is because this level serves a niche market that offers value with technology that is based on fundamentally new knowledge. This level is characterised as fast and dynamic and is not limited by sunk costs of investments or any boundaries of the current technology. In this level, multiple technologies can develop at the same time (Markard & Truffer, 2008). Overtime, these niche technologies can break out the niche level into a new ST-regime if there is a window of opportunity, this is illustrated in Figure 3.1 by the arrow pathway. These windows of opportunities occur when processes at landscape-level and ST-regime are disturbed due to tensions in the ST-regime or by shifts in the landscape which put pressure on the regime (Geels, 2002). During this shifts, different technologies are linked together to form a new regime. Consequently, not only the technology is changed but also wider dimensions such as industry network and regulations (Geels, 2002).

Although this framework gives a good overview of the current situation, it lacks to describe the dynamic change when innovations breakthrough to the regime level. Elzen et al. (2012) state that radical innovation or the transition of a ST-regime is described as coincidental and sudden. Given that technological advances mostly occur over time and trajectories are s-shaped (Schilling, 2019), a sudden transition is unlikely. To better understand the dynamics of an transition in the ST-regime, Elzen et al. (2012) introduced *anchoring* as a new theory to describe the complex dynamics that shape the transition.

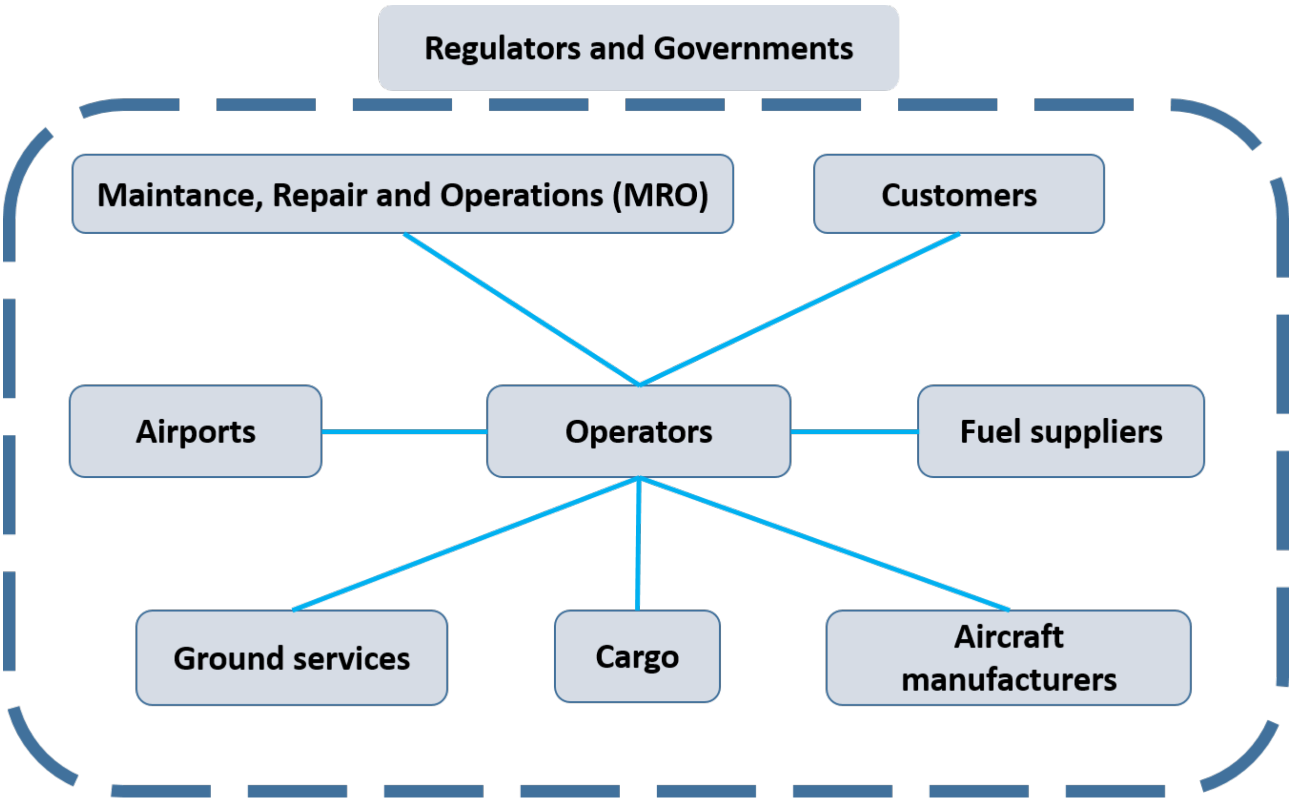

Figure 3.2: Overview of the actors in the current aviation dominant regime. Boundaries for the regime are set by governments and regulators such as the EASA and ICAO.

3.1.1. Anchoring

Anchoring is defined as the process in which novelties connect or reconnect to the niche or regime (Elzen et al., 2012). A novelty is either a new technology, concept, or method of handling things (Elzen et al., 2012). The higher the frequency of anchoring occurrences, the stronger connections get and become more durable (Elzen et al., 2012). Anchoring takes place in environments with uncertainty were ties can be broken easily and comes in three forms: technological, network, and institutional, depending on the novelty that appears in the system (Elzen et al., 2012).

The appearance of new anchoring situations can also be seen in the light of probing new ideas. By trial and error different actors are exploring new relations and links to come to a new configuration that fits the innovation. With this view, it is also understandable that new entities, either individuals or organisations can be key to form durable new linkages. Similarly, when links become robust in network of actors, the loss of an individual actor will not harm the process of innovation as the links in the system become resilient (Elzen et al., 2012).

Anchoring can take place in either the regime or in the niche, however, in most situation a clear distinction cannot be made for the level in which the anchoring takes place (Elzen et al., 2012; Smith, 2007). In other words, the clear cut between levels as described in the MLP by Geels (2002) may not be reflective to reality. Smith (2007) explained this issue as:

> *Whilst this multi-level model has heuristic value, in practice niche-regime distinctions are rarely so clear cut. Distinctions soon break down, as socio-technical components, but not entire alternative practices, translate from niches into regimes and components of each appear in the other. (...) Without rejecting the multi-level model, the findings here do stress the need for closer attention to relations and translations between levels.*

As can be seen, the MLP is useful to obtain an abstract view on which transitions could take place, but lacks to explain the complex dynamics between the niche-level and the socio-technical regime. Seen from the perspective of the MLP, radical innovation is reserved for the niche-level in which institutions are seen as external parties as they belong to another level (Markard & Truffer, 2008). It is therefore questionable if the dynamics of technological transitions can fully be explained by solely the MLP. To extend the MLP, this thesis also considered the TIS by Bergek et al. (2008).

3.2. Innovation system

Different from the MLP, the TIS focuses on the development of emerging technologies and the networks around the emerging technologies (Bergek et al., 2008), rather than the current regime which can be disrupted. The widely adapted definition of a TIS is: ... "*network(s) of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse, and utilise technology*" (Carlsson & Stankiewicz, 1991). Hence, this model is able to capture the knowledge that the technology embodies as the knowledge is mostly in the network and interaction of several actors (Hekkert et al., 2007).

Similar to the MLP framework, the TIS comprises actors, institutions, and networks (Bergek et al., 2008). Actors represent firms that enter the value system. E.g for aviation this could be manufactures of new engine types, future fuel companies, or NGO's (Bergek et al., 2008). Besides these type of firms, knowledge institutions such as universities are also part of the actors. New actors that enter the system mostly fill knowledge or resource gaps that are needed to link multiple actors. New knowledge is based through these entrees (Bergek et al., 2008).

Networks in the TIS can be of varies types. A learning network link several actors to exchange tacit knowledge and resources and enhance information exchange (Bergek et al., 2008). This type of network gives also shape to the future of the system as they exchange expectations and possibilities between the actors. Another type of network is advocacy coalitions. In these coalitions like minded actors try to influence the political agenda to gain ground (Bergek et al., 2008). New actors have to fit into these network to contribute to the TIS.

The last entity in the TIS are institutions. These consist of regulators and governments (Bergek et al., 2008). Institutions determine the rules and norms in which the TIS operates. The change in the institutions cause new technologies to gain momentum as these moments have fluid norms and regulations (Bergek et al., 2008).

The innovation system framework can be applied for different levels of analyses. Four forms are found in literature: the national-, the regional-, the technological-, and sectoral system of innovation (Markard & Truffer, 2008). Delineation of a system is hard, especially for radical innovation, as the developments of these innovations are intertwined and cross boundaries (Markard & Truffer, 2008). For this study, the focus will be on the TIS. This form was assumed to be the most appropriate as the development of sustainable propulsion technologies are across multiple sectors and also cross spatial boundaries.

3.2.1. The seven functions of the innovation system

Although the TIS already out more emphasis on the dynamic character of innovation, it does not a provide an explicit framework to evaluate the dynamics of the innovation process. To make the model more explicit, Hekkert et al. (2007) proposed seven functions of the innovation system including three motors to explain the innovation process, and thereby the potential of the innovation to develop in a new regime. An overview of the seven functions and their interaction are given in Figure 3.3. The key of the seven functions is to explain how emerging technologies breakthrough and become successfully adapted. As Figure 3.3 shows, the functions do also influence each other.

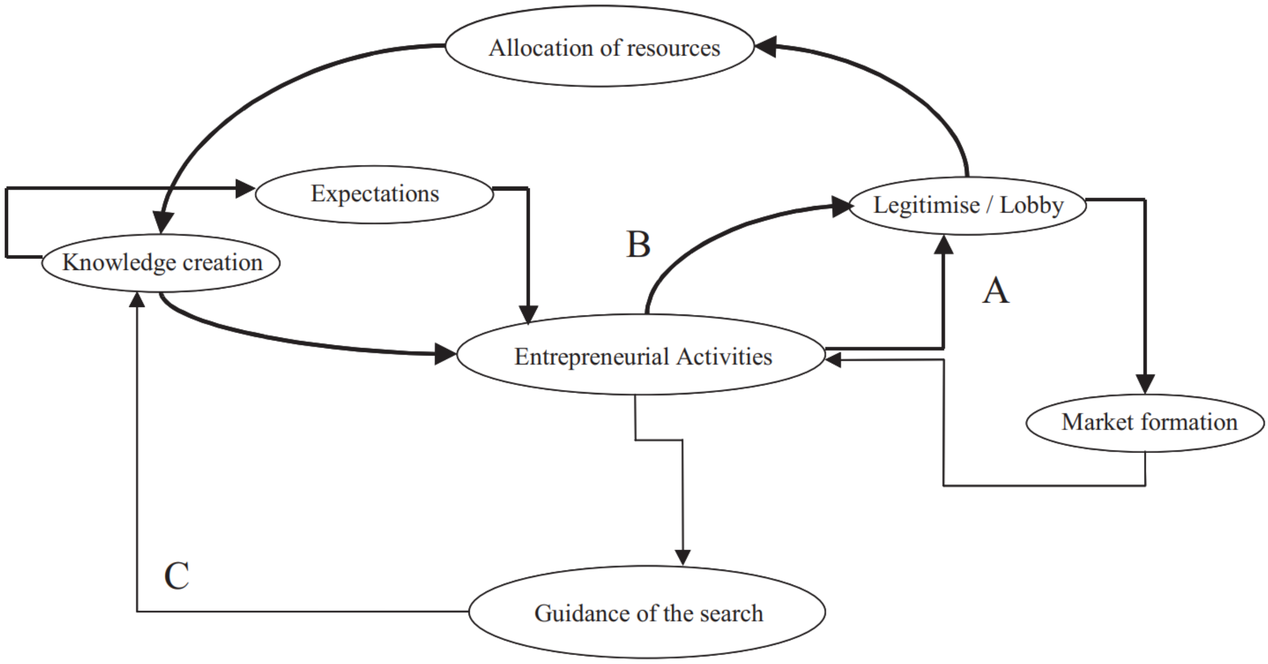

Figure 3.3: Seven functions of an TIS and their interaction (Hekkert et al., 2007)

Entrepreneurial activities

This function consist of either new actors or incumbent players that actively seek to leverage novelties to create new markets (Hekkert et al., 2007). The activities in this function entail risk but this risk is needed to explore new combination of technical knowledge, markets, and applications. Although these activities expose actors to a significant risk, these activities also increase learning and knowledge creation.

Entrepreneurial activities are centred in the middle of Figure 3.3. The reason for this is is that entrepreneurial activities highly depend on the other six functions in the model. When the other functions are flourishing, the environment will attract new actors and incumbents to act on the opportunities created by these functions (Hekkert et al., 2007).

Knowledge creation

At the heart of innovation is new knowledge. To obtain new knowledge research and exploration need to be performed. Hekkert et al. (2007) therefore states that R&D investment, R&D activities, and patents are indicators of the knowledge creation within the innovation system. This function encompasses learning by doing and searching (Hekkert et al., 2007).

Expectations

To exchange information on what knowledge is created, networks are considered to be very important. Networks consist of a variety of actors forming a heterogeneous environment, creating new linkages between actors and rules set by policy (Hekkert et al., 2007). Similarities of this network can be seen in the theory of anchoring by Elzen et al. (2012). Knowledge spreading within this networks will result in expectations in the innovation system.

With knowledge creation, expectations of certain processes or innovations are set. The actors in the innovation system will shape expectations and predictions on the future of certain knowledge developments. Consequently, they will align there entrepreneurial activities, Figure 3.3 (Hekkert et al., 2007).

Guidance of search

Guidance of search reflects focus on only a few fields of research. To make significant progress in specified field of unexplored territory of knowledge, enough resources should be available. The availability of resources is, however, always limited. A proper focus on a limited number of projects is therefore necessary to make proper progress in knowledge creation (Hekkert et al., 2007).

The direction in which search is performed is determined by societal norms and trends. The guidance is an interactive function and varies over time. Initial guidance is set by vague ideas and are shaped by society, governance, and market (Hekkert et al., 2007).

Market formation

Market formation for new innovations is, initially, difficult as it means that it has to compete with incumbent technologies. First of all, new products or technologies are more expensive than existing technologies. Where incumbent products can leverage economies of scale and rely on the existing infrastructure, new technologies have small production numbers and logistics are not optimised yet, making them more expensive. Secondly, new technologies are most often inferior in terms of performance (Schilling, 2019). An example can be seen with the first electric cars. The range of these vehicles was relatively short making them impractical to use. This is the reason that new technologies develop in protected niches as they can hardly compete with the existing regime (Hekkert et al., 2007).

By developing a technology in a protected environment, knowledge can be created and developed. With increasing knowledge and technological development new markets can be created as new technology add additional values compared to the old technologies. Overtime, innovations will obtain a competitive advantage and increase the demand for the product (Hekkert et al., 2007).

Allocation of resources

As discussed in the function of knowledge creation, the sufficient allocation of resources to develop new knowledge is key. Therefore, this function is the most important input for knowledge creation. Resources can be either in the form of human capital or financial capital. For financial resources, innovation systems rely on R&D investments or funds. These financial injections are particularly important as it allows for experimentation (Hekkert et al., 2007).

Legitimise/Lobby

The last function is to legitimise the technology. The current regime has actors that are heavily invested in the old technology, counter acting on new technologies that will disrupt the current market. It is therefore important that actors in the innovation system to form advocacy coalitions (Hekkert et al., 2007). By doing so, incentives to transition from technology can be accomplished. Measurements that can help to do so could be tax advantages or legislative advantages (Hekkert et al., 2007).

When these coalition gain track and grow in size, the become powerful enough to overthrow the existing regime, leading to a technological transition. The potential of success of a coalition depends on the available resources and the expectations. To manage these, again lobbying can be of great influence to mobilise resources and create attention (Hekkert et al., 2007).

The motors of innovation

The interactions between the functions can be seen in different forms. The initiation, however, often occurs at a smaller group of functions. First, the *guidance of search* is often an initiator of innovation. With the guidance, resources are mobilised and expectations for a particular innovation will rise, motor

C in Figure 3.3. Secondly, a start of a virtuous cycle is seen for *lobbying*. Entrepreneurs lobby for more resources, leading to initiation of motor B, Figure 3.3, or they try to create new markets, motor A Figure 3.3.

3.3. Organising for innovation

Schilling (2019) identified several factors for innovation that relate to the size and structure of a corporation. Factors include: *Centralised vs. decentralised*, *formalisation and standardisation*, and *mechanistic vs. organic structures*.

3.3.1. Centralised vs. decentralised

The difference between a centralised and decentralised structure is the level of authority where decisions are made. In centralised organisations, decision making is done in the top-management level whereas decision making in decentralised organisations is pushed down (Schilling, 2019). Both have their pitfalls and benefits.

Decentralised organisations reap the benefit to produce solutions that fit closely to their operations. These type of firms also take advantage of the diverse knowledge of department and the market contacts of different divisions. With this, decentralised R&D firms show a more diverse projects and also more projects (Damanpour, 1992; Schilling, 2019). A risk of this approach is that different divisions have the same need and will initiate similar projects without communicating. As a results, the learning-curve maybe less steep and resources are wasted (Schilling, 2019). This type of organisation was mostly seen in highly volatile markets or with companies that need to adapt to different markets (Schilling, 2019).

Centralised organisations perform R&D in a single department. In contrast with a decentralise approach, this form reaps the benefits of resource optimisation and faster learning-curves through development of multiple projects (Schilling, 2019). However, problems could occur with the solutions offer to each division because innovations may not be a ”one size fits all”. Firms that use this type of organisation are mostly firms that leverage a particular competency (Schilling, 2019).

3.3.2. Formalisation and standardisation

These concepts represent the rules and uniformity in an organisation. The higher the level of formalisation and standardisation, the higher the operational efficiency of a company (Schilling, 2019). Although the operational efficiency may benefit, innovation in the company is mostly suppressed because firms become rigid (Schilling, 2019). Highly formalised and standardised companies mostly fulfil high quality to the customer, such as an airline like KLM.

3.3.3. Mechanistic vs. organic structures

The balance and combination of formalisation and standardisation is mostly referred to as mechanistic structure (Schilling, 2019). These structures are known for their operational efficiency and well-oiled machine that performs consistently and is reliable. This type of firm could be recognised in airlines in general. Incumbent airlines strive for operational efficiency and try to deliver a reliable and consistent service to the customer. However, the downside of the high operational efficiency is the minimisation of variation which interferes with the possibility to be creative and foster new innovations (Schilling, 2019).

In contrast of mechanistic structures are organic structures. These type of firms are more latitudinal and have low levels of standardisation. Employees are highly responsible for their job. This structure allows employees to devote time to find new things and form teams to research organically emerged projects (Schilling, 2019). The operational efficiency of these firms is low.

Because airlines must have a high operational efficiency to be successful and deliver a reliable and consistent quality to the customer, high level of organic structure are less likely to create a successful airline. Large companies that face similar friction in their approach for innovation mostly organise the business in an ambidextrous organisation (Tushman & O'Reilly, 1996). In this kind of structure, organisations can be separated in a rigid and operational efficient part and a part that organise for innovation that is less bounded to the daily operations (Schilling, 2019; Tushman & O'Reilly, 1996). This type of firms deliberately choose to optimise short-term efficiency and long-term innovation (Schilling, 2019).

3.3.4. Organising for innovation in an airline

Because the operational efficiency that is needed within a company like KLM, an ambidextrous approach seem most suitable to innovate without compromising on reliability and consistency. Emphasise should be made in the type of innovation a service company can be made. KLM is a service company that delivers transportation of goods and passengers. Therefore, KLM heavily relies on manufacturers and partners for technological innovations such as sustainable technologies. Innovation in these business are seen in four categories (Miles, 2008):

1. Service concept: new value proposition
2. Client interface: changing the clients involvement
3. Service delivery system: changing the way in which service is delivered to the client
4. Technology: technological advancements are made that increase operation efficiency by enhanced motors and energy delivery.

Based on the paper of Miles (2008), it is expected that the new propulsion technologies will most probably interfere with all four categories; changing the way of air transportation. These kind of innovations can be seen as radical. Rather than the traditionally organised R&D activities, these kind of innovations have most success when treated opportunistically as a by product and is created in project-based teams (Miles, 2008).Schilling (2019) identifies four type of teams, Figure 3.4. The choice or best fit for a dedicated team depends on ten characteristics according to Schilling (2019), Figure 3.5.

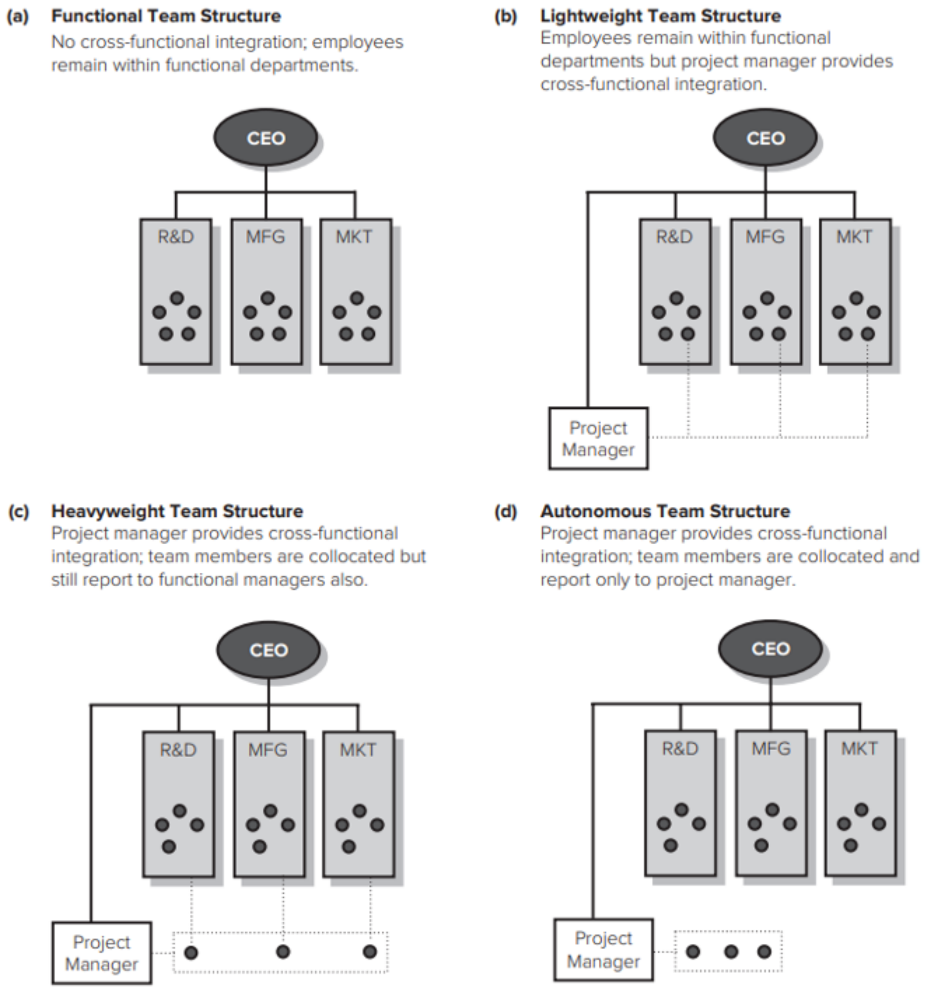

Figure 3.4: Overview of the team formation by Schilling (2019)

Characteristics	Functional Team	Lightweight Team	Heavyweight Team	Autonomous Team
Project manager	None	Junior or middle manager	Senior manager	Senior manager
Power of project manager	NA	Low	High	Very high
Time spent on team activities	Up to 10%	Up to 25%	100%	100%
Location of team members	Functions	Functions	Collocated with project manager	Collocated with project manager
Length of commitment to team	Temporary	Temporary	Long-term but ultimately temporary	Permanent
Evaluation of team members	Functional heads	Functional heads	Project manager and functional heads	Project manager
Potential for conflict between team and functions	Low	Low	Moderate	High
Degree of cross-functional integration	Low	Moderate	High	High
Degree of fit with existing organizational practices	High	High	Moderate	Moderate-low
Appropriate for:	Some derivative projects	Derivative projects	Platform projects/ breakthrough projects	Platform projects/ breakthrough projects

Figure 3.5: Criteria to assess best team fit

3.4. Conceptual framework

3.4.1. Macro-level perspective

Both presented frameworks, MLP and TIS, have a similar objective: explain the transition of emerging technologies to become the new dominant regime with the theoretical foundation of actors, institutions, and networks (Bergek et al., 2008; Hekkert et al., 2007; Markard & Truffer, 2008). The main difference is that the MLP lacks an understanding of the dynamics of an emerging innovation (Elzen et al., 2012). Because this thesis aims to understand the barriers and opportunities to deploying sustainable aviation, the dynamics in the innovation system were assumed to be substantial. The TIS model is assumed to be more suitable for the macro-level perspective of this study.

To better understand the dynamics within the system, this study will use the seven-function model of Hekkert et al. (2007). The seven functions will be used to understand the dynamics of sustainable technology development in the aviation industry. The functions are labelled F1 to F7. This study will investigate the current state of each function and the motors described by Hekkert et al. (2007) of an innovation system to obtain an overview of the macro-level perspective. The functions will be explored with industry experts in aviation. Hekkert et al. (2007) state that the positive feedback loops of motors A, B, and C are crucial for a well-functioning innovation system. Initiators of those motors are considered to be functions F2 and F6. By analysing each function's state and the motors' performance, this study will identify potential barriers and opportunities in the technology innovation system for sustainable aviation. Additionally, potential transition pathways for carbon-neutral aviation will be sketched based on the findings.

3.4.2. Micro-level perspective

In addition to investigating the seven functions, a micro-level perspective of the transition towards sustainable aviation will be explored. The micro-level perspective will be explored as a case study at KLM. The internal entrepreneurial activities will be considered, as well as how KLM organises innovation. The entrepreneurial activities of KLM will be reflected on the results of the macro-level perspective. The findings on how KLM organises innovation will be reflected on the theory from Schilling (2019) to reveal opportunities and barriers from a micro-level perspective.

With the perspective on the macro and micro-level of the transition, this study will reveal an in-depth understanding of the opportunities and barriers to deploying sustainable aviation. The findings will be used to make recommendations for multiple actors in the TIS. Figure 3.6 gives a visual representation of the conceptual framework of this study.

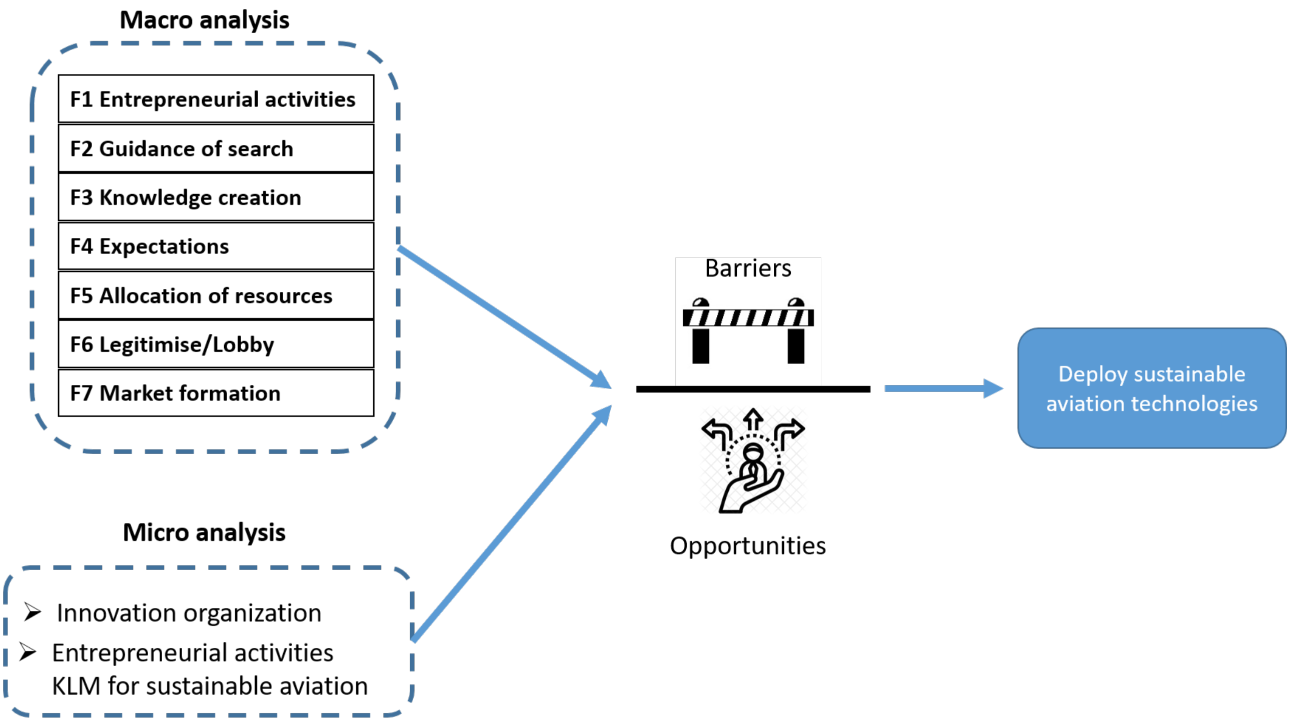

Figure 3.6: Overview of the conceptual framework used in this study. Functions of the model by Hekkert et al. (2007) are labelled F1 to F7.

4

Methods

4.1. Research approach

This study aims to map the barriers and opportunities in the transition towards sustainable aviation from a macro and micro perspective. Therefore, the objective is to better understand the internal organisation for innovation, the current activities for sustainable aviation, and the state of the innovation system's functions according to the view of industry experts. To fulfil this objective, the views of industry experts and innovation managers at KLM were collected in an exploratory research. An exploratory approach was chosen because I had little knowledge of the aviation industry and because the aim was to map the innovation activities of KLM and the current state of the innovation functions of the TIS according to the view of industry experts. The objective of exploratory research is to better understand a situation or problem rather than to provide a singular solution for a problem (Dudovskiy, 2016). As this coheres with the study's objective, an exploratory approach was considered the most suitable.

This study used a qualitative approach to obtain an overview of the innovation system's functions, macro level, and internal innovation organisation of KLM, micro level. The macro level and micro level data collection involved interviews with industry experts. Possible industry experts included start-ups, fuel producers, consultants, government employees or other related experts in sustainable aviation. These experts can be considered either actors or institutes in the TIS (Bergek et al., 2008; Carlsson & Stankiewicz, 1991). The data will be used to identify parallel views and factors that shape the state of each function.
Innovation directors/managers or program managers for sustainable innovation within KLM were chosen as suitable to perform the research on micro-level as the aim was to map the current innovation strategy and the organisation of KLM. The interviews for the research on micro level will be used to obtain an overview of the current innovation activities within KLM.

4.2. Macro level: TIS

4.2.1. Data collection

The data collection for the functions consisted of semi-structured interviews. The method of semi-structured interviews was chosen because of the exploratory objective and to brief the participants (Aldersey-Williams et al., 2020). Also, the semi-structured set-up kept interviews in this study's scope: hydrogen, battery-electric, and SAF aviation. Appendix B includes the complete interview guide used during the semi-structured interviews. The semi-structured method allowed for deviation from planned structures and themes if the participant brought up new information. A downside of this approach is that results between participants are difficult to compare because questions and topics discussed during the interviews differ in every case. Nevertheless, this method appeared suitable to extract the current state of the functions from different angles and to obtain a balanced view. Interviews were conducted in Dutch, as this was the mother tongue of all participants. This choice of language enhanced the quality of the interviews as participants could better express themselves.

The researcher conducted all interviews online using Microsoft Teams, as this was the preference of the participants. All interviews were recorded by phone, after which transcriptions of the recordings were made. Recordings were deleted after the completion of the transcription.

Participant selection

The participants for exploring the innovation system's functions were contacted with the help of KLM's network. Participants were selected based on their relevance to the innovation system and their perceived knowledge of the aviation industry. KLM's on-site supervisor of this thesis proposed several candidates that were contacted. In collaboration with the on-site KLM supervisor, various actors, start-ups, consultants, and policymakers were contacted. The final participant group were eventually selected based on their availability.
In total, eight interviews were performed with industry experts within the TIS, Table 4.1. Upfront, a summary of the aim of the study was sent to give interviewees context and an understanding of the seven functions, Appendix A. Because the interview results included the interviewees' personal views and opinions, interviews were anonymised.

#	**Category**	**Function**
P1	Start-up	Co-founder
P2	Stakeholder of the industry	Airport sustainability manager
P3	Start-up	Co-founder
P4	Consultant aviation industry	Partner
P5	Start-up	Founder
P6	University	Professor TU Eindhoven
P7	Government	Sustainability manager
P8	University	Professor TU Delft

Table 4.1: Overview of the industry experts in this research for the functions of the innovation system

4.2.2. Data analysis

Recordings of the industry expert interviews were transcribed and analysed using Atlas.Ti. Atlas.Ti offers analysing tools that can be used to code interviews and seek common themes. The transcriptions were non-verbatim: stutters and noises would not be transcribed. Recordings were transcribed in Dutch to prevent information loss due to translation interpretations. However, the quotes used in the result section were translated into English. Participants' quotes were translated in the result section to deliver the key message rather than a verbatim translation.

Given this study's exploratory characteristics, open coding was used for the analysis. All interviews were coded consecutively. If new codes appeared, other interviews were checked if similar data appeared that could fit the same code. After completion of the open coding, obtained codes were organised according to the functions in the conceptual framework.

With the results of the interviews, an overview of the current state of the functions in the innovation system concerning sustainable aviation could be described. The results were used to answer subquestion 2 and 3: the potential pathways were constructed and reflected upon the functions and motors of the innovation system.

4.3. Micro-level: KLM

4.3.1. Data collection

Three internal interviews were conducted. The study aimed to obtain primary data on the innovation activities within KLM to reconstruct how KLM organises innovation and how the internal experts experience the innovation process in KLM. Furthermore, the primary data of the functions was discussed with the zero-emission aviation program manager to reflect the results in the view of an airline. Again, interviews were semi-structured. Themes that were discussed included the innovation activities, how KLM organises innovation, and how the interviewees experience the innovation projects/activities.

Participant selection

The interviewees for the micro perspective were contacted with the help of KLM's online supervisor. Participants needed to be managers or superiors to that position. Because the aim was to create an overview of activities and innovation strategy, it was assumed that managers and employees with superior positions would be knowledgeable on these subjects. Two innovation managers from different departments were interviewed, and one program manager of the zero-emission aviation program. Table 4.2 shows an overview of the KLM participants. Again, participants were anonymised.

#	**Department**	**Function**
E1	Innovation program	Director
E2	E&M	Innovation manager
E3	Fleet services	Program manager zero emission aviation

Table 4.2: Overview of the experts of KLM interviewed in this research for the micro-level perspective

4.3.2. Data analysis

Similar to the primary data analysis of the functions, recordings were transcribed. Again the recordings were transcribed using a non-verbatim method. The analysis was split in two parts: KLM's innovation organisation and the innovation activities within the scope of sustainable aviation. The interviews with E1 and E2 were used to understand the current strategy of innovation at KLM. The interviews of E1 and E2 were not coded because the interviews were used to map the innovation strategy of KLM. Because this does not involve opinions or views but facts, coding was not assumed to be suitable. Rather, a reconstruction was made of the innovation strategy. The reconstruction was send to E1 and E2 for verification of the results. The results of these two innovation managers were reflected with the theory of Schilling (2019) to evaluate the innovation strategy of KLM.

The aim of interview E3 was to obtain the innovation activities of KLM concerning sustainable aviation. The obtained codes from the macro-analysis were used to code the interview with E3. Similarities were searched with the results of the industry experts. The activities were compared with the overview of the functions' state and the innovation system's motors. The aim was to identify barriers and opportunities from an airline's perspective to contribute to the transition towards sustainable aviation. Additionally, literature that described the technological transition in other industries was considered to see what factors could be considered in the aviation industry's transition.

5

Results

This chapter will discuss the findings of the semi-structured interviews with the industry and the interviews with internal innovation experts of KLM. Section 5.1.1 in this chapter will display emerged codes from the industry experts and the organisation of the codes to the corresponding functions. Section 5.1.2, will discuss the current state of each function and motors of the TIS. Section 5.2 will discuss the interview results with the internal experts of KLM.

5.1. Macro-level results: the seven functions

5.1.1. Organisation of the codes

In total, 36 codes emerged from the interviews with the industry expert. The number of new codes dropped after interviews P1 and P2. The interview with P8 did not result in new codes, Figure 5.1. With the low number of occurring new codes and no new codes with P8, it was concluded that data saturation was reached. Based on the information in the codes, codes were categorised in the corresponding function of the TIS in the conceptual framework. Figure 5.2 shows the categorisation result. Several codes were assigned to multiple functions as their influence was overarching.

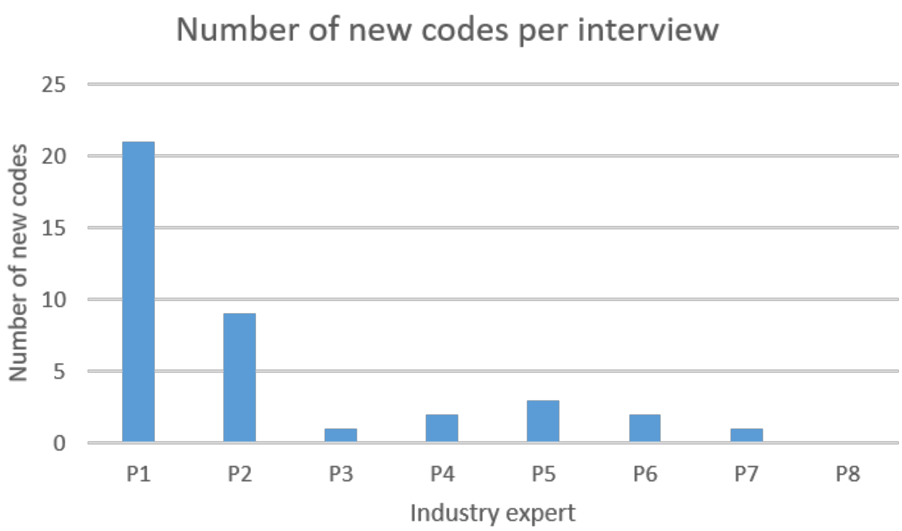

Figure 5.1: Visual representation of the number of codes that emerged with each industry expert interview

F1 Entrepreneurial activities
- Entrepreneurial activity
- Collaboration
- Opportunity as frontrunner
- Sustainable motivation for entrepreneurship
- Regional differences
- Regulation
- Price of new method
- Credibility

F2 Guidance of search
- Climate
- Living environment
- Regional differences (Barrier)
- Technical preferences

F3 Knowledge creation
- Knowledge creation
- Collaboration
- Technological innovation
- Regional differences (Barrier)
- Technical preference

F4 Expectations
- New mobility network
- Similarity automotive industry
- Synergy of technologies
- Technical advantage
- Synthetic fuel
- Infrastructure challenge
- Regional difference (Barrier)
- Supply challenge
- Technical disadvantage

F5 Allocation of resources
- Investors
- Subsidies
- Willingness to change
- Technical advantage
- Regional difference (Barrier)
- Reluctance regime
- Resource allocation
- Uncertainty

F6 Legitimise/Lobby
- Collaboration
- Legitimization opportunity
- Similarity automotive industry
- Willingness to change
- Legitimization challenge
- Regulation
- Reluctance regime
- Regime power
- Safety
- Technical disadvantage
- Technology preference

F7 Market formation
- Market formation
- Market opportunity
- Market stimulation
- New mobility network
- Regional difference
- Subsidies
- Willingness to pay
- Competition for energy other industry
- Price of new method
- Regulation
- Value-chain

Figure 5.2: Categorisation of the codes per function. Red marked codes were interpreted as barrier, green marked codes were interpreted as opportunity

The most frequently discussed codes were *regulation, market opportunity, collaboration, market formation* and *legitimisation*. A frequency distribution of the five most used codes can be found in Figure 5.3. Due to the semi-structured nature of the interviews, no value should be assigned to the distribution between participants. The results in Figure 5.3 are rather illustrative of the main topics discussed in the individual interviews.

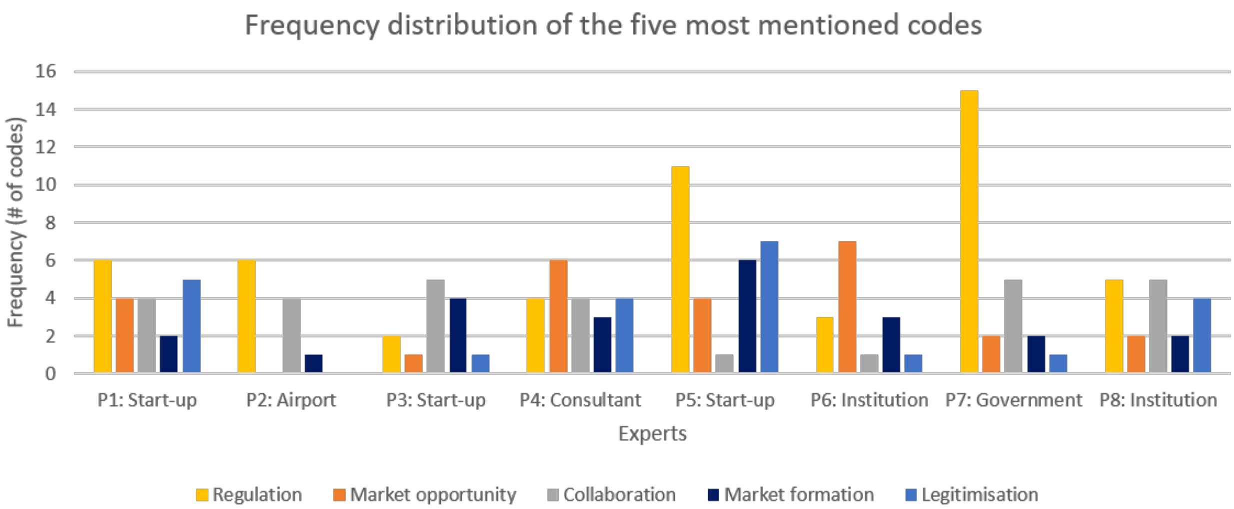

Figure 5.3: Frequency distribution of the five most mentioned codes

5.1.2. State of each function

This section will elaborate on the findings for each function and the motors of the TIS. Each function will be discussed separately, after which the motors of the TIS will be discussed. At the beginning of each function, a short table with key takeaway points is given.

F1 Entrepreneurial activities

Key points:
Opportunity
* Both new entrants and incumbents show entrepreneurial activities
* Multiple collaborations are present in the TIS
* Regional differences in opportunities, Scandinavia has great short-range potential
Barriers
* Start-up activities centre around battery-electric, incumbents on hydrogen
* Credibility influences activities incumbents

Entrepreneurial activities lay at the heart of a well-functioning TIS (Hekkert et al., 2007). The other functions of the model largely influence this function. Interviews revealed that there are many entrepreneurial activities by two types of *actors* within the TIS. The first type of actors is the incumbent actors of the current regime. Incumbents do undertake initiatives for sustainable aviation. All interviewees discussed that incumbent players like Boeing, Airbus, and Shell are trying to innovate towards sustainable aviation. P2, an airport sustainability manager, doubted the action pace of incumbents: *"Businesses that really want to change something have to turn around their complete revenue model"*. P3, P4, and P5 had a similar view and mentioned the need for a new business model for green aviation with battery-electric or hydrogen planes. From a start-up perspective, the intention of incumbent regime actors to become more green is seen as essential in the transition, start-up P1: *"There is a reluctance I do not understand... Major steps could have been taken if regime actors had taken a more active role in the transition"*. P7 and E3 explained: that safety is the core value in aviation. Because these technologies are still premature, existing companies cannot risk their credibility on safety. Program manager zero emission aviation, E3, mentioned: *"Only one mistake or accident can really affect our business"*

The second type of actors are start-ups or new entrants in the aviation industry. The types of new businesses that were discussed varied between green flight academies, aircraft manufacturers, completely new zero-emission operators, and MROs. All start-up interviewees (P1, P3, and P5) have activities for battery-electric aviation. When asked what their motivation was to commence entrepreneurial activities for battery-electric aviation, the unanimous answer was sustainable responsibility. Additionally, start-up founder P5 mentioned that the business's success is partly focused on contributing to knowledge creation and showing feasibility.

P1, P3, P4 and P5 saw market potential for a new manner of transport by air for battery-electric aeroplanes. P2 and P4 argued that incumbents should also have a regulatory incentive to transition towards a sustainable model. However, government sustainability manager P7 discussed that these regulatory incentives would be preliminary in an early stage with no commercial aircraft.

An overarching theme that came forward in all interviews was collaboration. Several initiatives were mentioned such as Powerup, Duurzame luchtvaart tafel, and Elektrisch vliegen collectief. The collaborations included a variety of actors ranging from airports, government, airlines, and start-ups/scale. The purpose of the collaborations was to investigate the possibilities and challenges of hydrogen and battery-electric flying. SAF was not mentioned within the collaboration theme.

Interviewees also shared that regional differences influence entrepreneurial activities (P1, P2, p3, P5, and P7). P2 shared that there is a will to become sustainable in Europe and the Netherlands. Nevertheless, differences are already appearing between countries. P3 mentioned that Scandinavia, Germany, and Asia are much more focused on battery technologies than the Netherlands. These differences already create barriers in the ecosystems, according to P5. Therefore, all interviewees see collaborations as a major keystone in the transition. P2 mentioned: *"It is the art to collaborate to come to a new industry standard rather than a separated island."*

F2 Guidance of search

Key points:
Opportunity * All three technologies are of interest * Dutch guidelines are given in the Luchtvaartnota **Barrier** * Guidance is regional dependent * Public opinion also influences the search for solutions: living environment, climate, and noise.

Guidance of search gives direction to the transition process and is initially steered by vague ideas of society and governments. In the interviews came forward that climate-driven policies give guidance. Government manager P7 mentioned that there are guidelines for the aviation industry in the Netherlands. The Dutch government communicates these guidelines in the "luchtvaartnota", which are based on an international agreement. P7 also emphasised that international standards guide commercial aviation but that these are comparable with the guidelines in the "luchtvaartnota".

Besides guidelines from the government, guidance is also influenced by the public. Professor P6 debated that the public opinion on aviation is negatively oriented: *"People associate air transport as a major contributor to the climate problems we face."*. In general, interviewees recognised that public opinion forces the current industry to rethink its method of operating. Values that were mentioned as important by P1, P3, P6, and P7 were safety, living environment, climate, and noise pollution.

Guidance of search was also experienced as regional dependent. This mainly applies to research for hydrogen and battery-electric options. Start-up P3 said: *For instance, The Netherlands wants to become a hydrogen economy but the focus in Germany and Scandinavia is more centred around battery technology*. Airport sustainability manager P2 agreed that hydrogen is preferred in The Netherlands because hydrogen is seen as the new energy carrier in the transition.

F3 Knowledge creation

Key points:
Opportunity * Knowledge is created for all three technologies * New knowledge for secondary technologies is also created **Barrier** * Less knowledge creation for infrastructure, but initiatives are taken * The knowledge creation of hydrogen and battery-electric technologies is regional dependent * Test environments are scarce, but the Dutch government is exploring opportunities to facilitate testing airspace

The knowledge creation for zero-emission aviation mainly focuses on the aircraft rather than the infrastructure needed to support zero-emission aviation. The interviews revealed that the infrastructure for the sustainable aviation age is under investigation. For instance, start-up P3 doubted the feasibility of hydrogen aviation because the transport of hydrogen to airports is expensive and inefficient in the current state of knowledge. Incentives and initiatives for creating knowledge and infrastructure for new technologies were found with P4, P6, P7, P8, and E3.

The knowledge that emerges from the academic world is regionally dependent. Differences were observed between university professors P6 and P8. P6 indicated that more battery-electric research appeared, in contrast with P8, who saw more information coming from hydrogen technologies.

Start-ups P3 and P5 also experienced difficulty testing new aviation technologies, which was seen as a barrier. Both agreed that this was due to safety reasons. This finding was discussed with government sustainability manager P7 who said that the government is discussing making airspace available in the Netherlands. Consultant P4 also argued that there is an opportunity for the government to give up some airspace reserved for the military to test battery-electric and hydrogen solutions.

Besides knowing how to fit battery-electric and hydrogen solutions on an aircraft, secondary knowledge also emerges according to P6 and P8. Secondary knowledge includes production techniques of green hydrogen, CO_2 capture technologies for producing synthetic jet fuel, non-CO_2 effects of combusting hydrogen, and increasing battery energy density. P4, P6, and P8 felt that these enhancements are crucial for the scalability of sustainable solutions.

F4 Expectations

Key points:
Opportunity * Future of aviation is a synergy of hydrogen, battery-electric, and SAF * Battery aviation is expected to satisfy a new market rather than compete with traditional aviation **Barrier** * Major obstacles are seen for hydrogen logistics and technology * The opinion of battery-electric varies among participants * The belief among participants is that incumbents focus more on hydrogen and new actors on battery-electric

Expectations emerge from *networks* in the TIS. Expectations mainly guide incumbent and new entrants to act on entrepreneurial opportunities. As discussed earlier, collaborations are active in the TIS. The common expectation among all interviewees was that the transition towards sustainable aviation would emerge in a synergy of hydrogen, battery-electric flying, and SAF.

All interviewees unanimously agreed that SAF is the solution for long-haul flights over 1500km as the current state of batteries and hydrogen technologies will not be ready in the coming 20 years (P8). The expectations for medium to short flights are undecided between hydrogen and battery aviation. Nevertheless, interviewees shared that battery-electric flights would solve short flights, and hydrogen would fill the gap between battery-electric and SAF distances. It was observed that interviewees favoured the technology of their interest. For instance, start-up P3 stated that hydrogen is inferior to battery-electric due to operational benefits and costs. University professor P8 disagreed: *"...entrepreneurs that favour battery-electric solutions do not include the short life cycle of the battery packages and the regular package replacement in their cost calculations."*. A unanimous expectation could not be determined for short to medium-haul flights. For ultra-short flights below 500km, there was consensus for the potential of battery-electric.

Interviewees expressed concerns with the logistics and operational support of battery-electric and hydrogen technologies. For hydrogen, the green production, transport, and (onboard) storage were of concern (P1, P3, P4, P5, P6). However, the targets and needed improvements for hydrogen are clear and feasible (P2, P8). For battery-electric, the path of improvements for batteries is also clear; however, the feasibility is doubtful, says P2: *"You cannot make fish climb a tree"*. With the statement, P2 displayed his concerns about the limits. P2 doubted the improvements that could be made to the current battery technology in terms of weight and energy density. University professor P8 agreed and added the batteries' severe climate impact.

Because of the limitations of battery-electric in terms of weight and energy density, it was expected by all interviewees that this would not replace existing intercontinental commercial flights. P3, P4, P5, P6, and P8 expected battery flights to open up a new market for ultra-short flights. Consultant P4 foresaw new direct routes that do not exist. P4 also mentioned that routes that were removed in the past could be reinstalled. These routes could be installed because of the lower operating costs of battery-electric aeroplanes. It was mentioned that battery-electric flights could take over some business trips that consume much time with the car (P4) or replace high-speed trains (P1, P6). Start-up founder P5 also saw a new market. P5 argued that the initial customers would likely be business workers due to the higher costs as these flights are low-scale. P5 expected the market to grow for battery-electric aviation, which will result in the next step in the adoption curve. The transition of the automotive industry shaped this expectation.

From the interviews, it appeared that there is a belief among all interviewees that incumbents do focus on hydrogen solutions while new entrants engage more in battery-electric technologies. The reason interviewees gave was the alignment with the existing infrastructure and business models between kerosene and hydrogen (P2, P3, and P5). In contrast, start-up founder P5 argued that start-ups are more technology-driven and seek opportunities that are now feasible. University professor P8 disagreed:

> "*The cowboys that argue battery-electric aviation has the potential for ranges longer than 300km have limited knowledge of the basic principles of aviation. The technological advancements that need to be made are not feasible or expected in the coming decades. Besides, they underestimate the climate impact and the cost to replace battery packages of that size, which they do not take into account in their pitches.*"
> - University professor, P8 -

F5 Allocation of resources

Key points:
Opportunity
* Resources are allocated to all technological projects
* Resources come from investments, funds, and subsidies
Barrier
* Several participants experienced reluctance in resource allocation of incumbents

Resources are allocated for the development of sustainable aviation. The study revealed that mainly financial resources are allocated that come from funds, subsidies, and incumbent investments. The national growth fund was the most mentioned national fund made available for sustainable aviation development in the Netherlands (P1, P2, P4, P5, P6, P7). Recently, 40 million euros were made available in this fund. However, airport sustainability manager P2 remarked on this fund because the money was only available for technical advancements that did not include the airport's logistics.

Interviewees recognised that incumbents also invest in the transition towards sustainability but that these parties are reluctant in their allocation (P3, P5). Most of them show a risk-averse approach seeking a return on investments. Start-up P1: *"The only reason we could refinance our business was that we showed that we have a running business which is a rather low risk. Moreover, we already invested a significant sum of private equity."*. Founder P5 confirmed that incumbents and investors are reluctant because there is no money made yet. Program manager of zero-emission aviation commented that the biggest concern is safety and reputation for incumbents. Therefore, investments should be thought through. Moreover, E3 mentioned that there is still uncertainty about how the transition is taking shape and how new revenue models should be shaped.

As start-up P1 mentioned, financial resources also came from private equity. These resources mostly came from selling other businesses. Start-up P3 also mentioned that they included several private equity stakeholders.

F6 Legitimise/Lobby

Key points:
Opportunity
* There is a will to adopt new technologies in the Netherlands and Europe in general
Barrier
* The existing regime has the power to steer legitimisation and lobby
* Public opinion is negative for aviation which makes it hard to introduce innovation
* No legislation is present to stimulate market formation

Lobbying, legitimisation, and the influence of the dominant regime were experienced as significant factors. An example of the regime's influence is that major players in the aviation industry approve subsidies. Start-up P3 said: "*We applied for a specific subsidy in which Shell was the chair of the approval committee. Although it was not the reason, we felt that Shell denied our grant because they have other interests.*". It was also asked if the start-up experienced that the regime obstructed them. Start-up P1 shared that he did not necessarily feel obstructed, but the regime did not help them either. However, interviewees experienced that the legitimisation of the battery-electric technology is suppressed.
P3 also mentioned that the Netherlands has a clear mission to become a hydrogen economy rather than batteries but that this did not influence the development of other technologies. Airport sustainability manager P2 shared the same opinion.

When asked if start-ups also tried to lobby, respondents stated that it took much effort to influence the decision-making process. To overcome the barrier, start-ups seek collaboration. Moreover, they try to get involved in parties like the "duurzame luchtvaart tafel" or form alliances with similar start-ups.

University professor P6 also shared that there is a significant barrier seen within the public opinion: *"Aviation is seen as a major contributor to the existing climate problems; however, this image is largely framed by media"*. To overcome the barrier and legitimise clean solutions, Start-up P1 seeks exposure in all media. P1 invited the minister of infrastructure to experience the battery-electric two-sitter at the start-up of P1.

To further legitimise battery flights, start-ups compared the transition with the automotive industry. They used this example as a guide for the aviation industry. The impact of these activities needs to be clarified.

Besides the new actors, also incumbents encounter barriers to legitimisation. E3 mentioned that it is tough for KLM to announce green initiatives as the public receive most of these with scepticism if KLM is not transparent about the project. The scepticism was a barrier to starting collaborations and commitments.

It was also argued that the regulation around aviation should be reviewed to stimulate market development. In the current political view, the number of flights should be reduced in the Netherlands. However, this policy is based on kerosene planes' current noise pollution problems. According to preliminary research results of P4, hydrogen and battery aeroplanes do not have these problems. Therefore, P4 opted to introduce new slots for battery-electric and hydrogen flights. Consultant P4 explained that this measure would make it attractive for existing airlines to adopt these new slots because they can increase their service by adapting to newly available slots by stepping into sustainable planes. When this finding was discussed with government manager P7, P7 indicated that this regulation was considered.

F7 Market formation

Key points:
Opportunity * Market opportunities vary per region and country * Market stimulation is considered a major opportunity to kick-start the sustainable aviation market **Barrier** * No market exists for hydrogen planes, a minimal market for small battery-electric, and a big market for SAF * Participants see barriers in the supply of green hydrogen and, consequently, SAF

Market formation is the initial space in which developments take place (Bergek et al., 2008; Hekkert et al., 2007). The battery-electric, hydrogen, and SAF market formation will be discussed separately. The market for commercial battery aviation does not exist in the Netherlands, besides the Eflight academy at Teugen. Scandinavia considers battery-electric aeroplanes due to the interesting geographic conditions and the short distance between isolated regions (P3, P4, E3). Additionally, P4, P5, P6, and P7 see opportunities to introduce battery flights at the ABC-islands.
According to consultant P4, battery aviation could restore abandoned routes in the Netherlands, such as Schiphol to Maastricht. The common thought of interviewees was that battery aviation would mostly enter a new market that does not fit the incumbent market of passenger aviation. The main reason was the range resulting from the battery's weight, its energy density, and the advancements that can be made with both (P8).

For a 100% hydrogen-fuelled aeroplane, no market exists in the Netherlands or other countries or regions mentioned in the interviews. Airport manager P2 mentioned that hydrogen would be a major energy carrier in the energy transition. Moreover, E3 mentioned the project with ZeroAvia, which is currently running to install the first flight from Rotterdam to London. Government manager P7 foresaw competition issues for green hydrogen in this light. P7 said: *"The availability of green hydrogen could also become a problem when other industries have a great demand."*.

For synthetic SAF, there is a big market which can be assigned to its drop-in characteristic, but issues occur for supply (P2, P3, P6). One of the resources for synthetic SAF is hydrogen (Bauen et al., 2020). As discussed earlier, the production of green hydrogen is still limited, and the production method of SAF is still expensive (P8, E2). As a result, current prices for SAF are at least three times as high as regular jet fuel (E2). The expectations for biological-based SAF, made from feedstock and oils, are low due to the scattered resource supply (P4). Moreover, these resources are more valuable for feeding humans (P2, P4, P5).

> "*At the moment, most of the SAF is bio-based. There is a big dilemma for feedstock, which can better be used to feed people. Therefore, advancement should be made with power to liquid (synthetic) in which hydrogen is used to produce eco-friendly kerosene.*"
> - Airport sustainability manager P2 -

Although it appeared from the interviews that a market is in a very early stage or does not exist, a frequently discussed theme emerged during the interviews: the stimulation of the market. Codes that linked to this theme were subsidies and regulation. The level of subsidies that the Dutch government grand to the development of the market is low compared to France and Germany, according to P7. P7 shared: *"The Dutch government prefer not to interfere with the free market and let the market does its work"*. P4 also suggested compensations for using SAF to stimulate airlines to use it and increase demand to stimulate the supply side to increase capacity. Another example was given by start-up founder P1. P1 suggested introducing similar structures that were used for electric cars. The government should make flying with batteries cheaper by providing subsidies to airlines to train their pilots in battery aeroplanes.

5.2. Micro-level: KLM case study

5.2.1. Organisational structure KLM

The organisation of KLM consist of three separate business entities: pax business, which comprises all matter related to passenger transport; cargo for the transport of goods; and E&M, also known as MRO, which is focused on repair and maintenance. These three entities are overarched by KLM corporate. Each business entity is divided into several divisions, Figure 5.4. In the structure, a hierarchic and mechanistic pattern was recognised. This could be a barrier for the innovation activities.

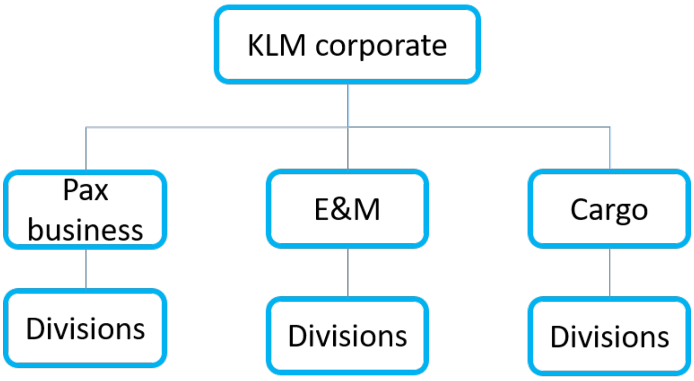

Figure 5.4: Overview of the business structure of KLM.

5.2.2. Innovation management KLM

This section is reconstructed from the interviews with E1 and E2 and was verified by E1 and E2. Currently, KLM has around 20 innovation teams, which are situated in the specific divisions of the three business entities. Besides the division-specific teams, there are also some overarching teams, such as the radical innovation team, part of the transformation office, BlueLabs, and technical innovation.

Barriers

From the interviews, it came forward that one of the major barriers to innovation within KLM is the high priority of daily operations. E1 shared: *"Everyone in daily operations, a major part of our business, worked day and night to fix every issue that emerged in the local crisis. This caused a low priority for innovation."*. E2 elaborated on the priority of daily operations. E2 explained that they encounter difficulties as an innovation team within E&M in engaging people to work on innovation projects. E2:

> "*In E&M, many people still have to check in with their card when they work. Because there is a strict policy for making your hours, people must be engaged to contribute to innovation. For instance, we held an innovation fair. To lure people from the floor, we planned the fair during their lunch break and offered free lunch otherwise, they simply do not come.*"
> - Program lead innovation E&M, E2 -

Interviews with E1 and E2 revealed that most people occupied with innovation assignments also report to daily operations. Again, both interviewees recognised that this lowers the priority for innovation. According to E2, only a handful of people had the liberty to only focus on innovation, and it was a very luxurious position. E2 also mentioned that because of the high priority of operations, innovation mostly sticks to enhancing current operations or making them more efficient.

Another obstacle that was experienced was championing the value-adding projects and killing value-less projects. One of the barriers that E2 experienced was the KLM culture in which it is hard to "kill

your darlings". E2 explained that many projects continue because there are no thresholds or milestones upon which projects can be reflected. Therefore, there is no clear cue when projects should be killed. In line with this finding, E2 proposed to install a venture board that monitors projects and assesses the projects' performance.
In line with the experience of E2, E1 experienced that the decision-making process for taking on projects is currently hard: "*Within KLM we tend to take on every project without critically looking if this contributes to our strategy.*" E1, therefore, mentioned that it has a high priority to obtain a clear strategy so that decisions can be made and resources are not wasted.

Opportunities
Although several barriers were recognised, E1 and E2 mentioned several initiatives to overcome some of these barriers. E1 mentioned that one of the priorities of the radical innovation department is to formulate an innovation strategy. A clear innovation strategy could contribute to solving the barrier of critically looking at what projects add value. With a clear strategy, employees are empowered to make coherent decisions within the perspective of the strategy.

A second opportunity was the current activity of the radical innovation team of E1, mapping all internal and external innovation projects. This activity aligns with the last opportunity of formulating a clear innovation strategy. Mapping an innovation ecosystem and formulating a strategic innovation roadmap prevents reinventing the wheel. Employees are also offered a platform, SharePoint, where people can exchange their ideas. E2 shared: "*Currently, people can bring in ideas to put a letter in the idea box, where it ends up in a giant pile that is whipped off the table by management. We want to change that.*". E1 added:

> "*In such a large company, it is sometimes hard to prevent reinventing the wheel in three different divisions. Our job is to be the bridge between the divisions and business entities. If someone at E&M is busy on something and someone at cargo is looking at a similar thing, you should collaborate to share your perspective and collaborate to develop a valuable product for the company as a whole.*"
> - Innovation program director, E1 -

Another activity to stimulate innovation within KLM is to educate employees on innovation. This program stimulates employees to evaluate their projects and is in line with the barrier of not killing projects that do not add value. The themes of the education are design thinking, Lean, and Agile. The education, in combination with a clear innovation strategy, would stimulate innovative projects among employees.
The last opportunity recognised in the interviews was collaboration. As explained earlier, one of the activities is to map external activities. KLM has much tacit knowledge of the industry and, therefore, KLM can be seen as the spider in the web. An opportunity was recognised as the industry's connector, linking like-minded parties and original equipment manufacturers (OEMs) to develop a sustainable industry.

5.2.3. KLM's innovation activities for sustainable aviation
The results of this section were based on the interview with program manager zero-emission aviation E3. E3 explained that the activities for sustainable aviation are currently in an explorative stage. This is applicable for hydrogen and battery-electric aviation. SAF is already implemented in the daily operations. The SAF is blended with the traditional jet fuel, according to E3 this mixture contains 0.5% SAF. For sustainable aviation battery-electric and hydrogen aviation should be separated from SAF because SAF is mainly a cost issue whereas the other two have technical obstacles. Therefore, the

focus of the project is on battery-electric and hydrogen technologies.

E3 shared that the board gave the program full liberty to explore all the possibilities for sustainable aviation. KLM displays a clear will to become the front runner for sustainable aviation.

> "*KLM has always be the front runner in new aviation technologies and models. Like the past 100 years, we want to be the front runner for the next 100 years. We realise that aviation is one of the causes of the current climate problems and we want to go back to a sustainable aviation model.*"
> - Program manager zero-emission aviation, E3 -

The project started with exploring the innovation eco-system for battery-electric and hydrogen projects. There were a lot of enthusiastic people and projects within KLM but also a lot of start-ups and incumbent aircraft builders. Because the technologies were assessed as premature, the main activities consisted of an exploration. To create an understanding of the current field of possibilities and to create solid base of knowledge of the technical possibilities, E3 explored the innovation-ecosystem. Preliminary findings of the exploration of sustainable aviation showed that urban air mobility and battery-electric could be part of future air mobility according to E3. E3 also shared that urban air mobility would not necessarily fit the business model of a major airline. Battery-electric, however, could be interesting but does not fit with the current hub and spoke model of KLM. The misalignment with the current industry could be seen as a barrier.

To explore possible new air mobility models, E3 shared that KLM is in several collaborations such as Powerup. Powerup is a collaboration of Dutch regional airports that look into the implementation and market formation for battery-electric flights. Collaboration was again major aspect in the current innovation activities. Nevertheless, no commercial certified aircraft does exist to fly passengers. Therefore, collaborations are limited to explore potential markets and create knowledge for infrastructure and networks.

A major concern for innovation for an airline is safety and reliability. E3 explained: "*As an airline there are very high standards and customers expect that we are reliable. A small accident could damage our reputation*". For that reason, E3 explained, an airline should be consciously aware on what to pursuit and what the effect is of our actions to keep up the high standards. A proper foundation of knowledge is therefore a must. Besides the core aspect of safety, the communication of commitments to sustainable projects should be handled with care according to E3.

> "*The airline industry is the image of pollution, therefore, every green initiative we announce is received with scepticism by the public. Moreover, when we do communicate these, the media will check if we keep our promises. Therefore, we can only publicly speak of commitments if we are 100% sure we can deliver.*"
> - Program manager zero-emission aviation, E3 -

6

Interpretation of the results

In this chapter the results will be discussed and reflected on literature. The motors of the TIS will be elaborated on. Furthermore, possible transitions will be discussed. Lastly, the observed barriers and opportunities for both the TIS and the internal innovation of KLM will be presented.

6.1. The performance of the technological innovation system

Based on the results, the state of each function was assessed. Green functions were assessed as good, orange as present but not optimal, red as minimally present and many barriers were observed. Figure 6.1 shows the interpretation of the state of the functions based on the results in chapter 5. The following sections will further elaborate on interpreting the functions and the motors in the TIS.

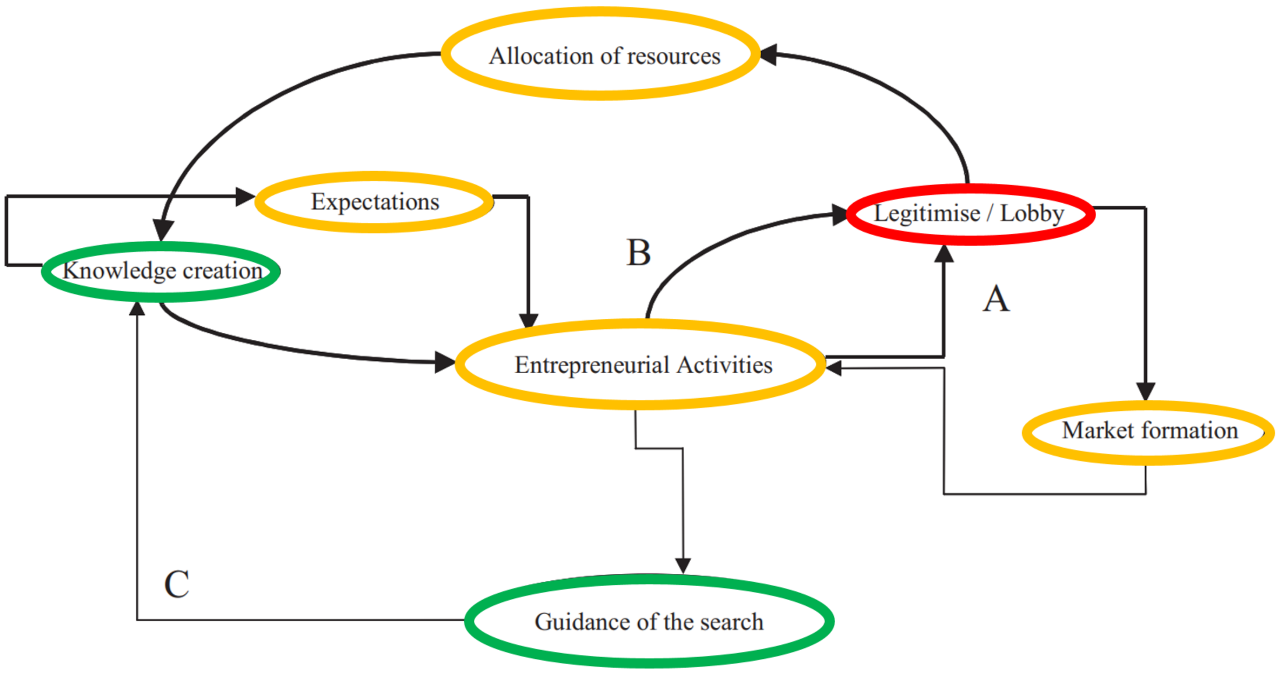

Figure 6.1: Interpretation of the functions in the TIS. I made the interpretations based on the results of this study. Green functions were assessed as present and contributing to the stimulation of the motors. Orange functions are present but not optimal. Red functions were assessed as minimally present or highly obstructed by barriers.

6.1.1. Motor A

Results showed that Motor A, which is initiated by lobbying/legitimisation to form a market and stimulate entrepreneurial activities, is only present for SAF. The other two technologies were assessed prematurely, according to most of the participants. There are no certified passenger hydrogen or battery-electric aircraft besides a two-seated battery-electric aircraft. Certification was recognised as a barrier that finds the root cause of the safety required for passenger aviation. These standards guarantee passenger safety, and standards are high. For that reason, it is not easy to introduce new technologies that do not match traditional technology, upon which the safety standards are based. A proper test environment to test new technologies could overcome this barrier. The interview with a government manager revealed that options are explored within the government.

Regulation and market stimulation was considered a major barrier and could be an opportunity to stimulate a market and, thereby, entrepreneurial activities. The only stimulation present was for SAF, which is currently only applicable in the Netherlands and will be rolled out in Europe. Multiple participants shared that an obligatory blend mandate forces the use of SAF. Regulations or simulations to make hydrogen or battery-electric attractive were absent. A reason given for this was the premature state of the technologies. Besides stimulation by the government, one example was also found for stimulation by an incumbent airline. American Airlines had ordered 200 electric planes from Heart Aerospace, while no production existed. Preorders by incumbents could be an opportunity to stimulate market formation directly. However, this kind of opportunity is capital-intensive and entails high risk. Reflecting on the TIS, this could stimulate motor A by the market formation and thereby stimulate entrepreneurial activities. Increased entrepreneurial activities could result in a steeper learning curve of an innovation Hekkert et al. (2007).

The function of legitimisation could be seen as a barrier to sustainable aviation. In the current situation, regulations are absent and have to be formed. Furthermore, the absence of stimulating regulations makes it less attractive to start these projects. However, as regulations are unclear, this opens up a window of opportunity according to the MLP framework (Geels, 2002). The window of opportunity was considered especially interesting, given the public's sustainable awareness. An opportunity was recognised for an airline to lobby regulations. The extensive knowledge of the aviation industry could be leveraged to optimise new operational models and shape regulations.

6.1.2. Motor B

Motor B, in which parties and actors lobby for more R&D resources to increase expectations, is currently still dominated by the incumbent firms of the regime. According to several interviewees, incumbents are interested in hydrogen solutions because of their similarity with their existing infrastructure. Multiple interviewees recognised that the incumbents located many resources to hydrogen. Also, incumbents have the power to influence the allocation of subsidies. Because incumbents hold power over the resource allocation, expectations were guided by the regime, according to the start-up participants of this study. They felt corporate businesses that were part of grant committees denied subsidy approvals when a particular technology, mainly battery-electric, did not favour the traditional business model.

Nevertheless, interviews revealed that smaller actors in the regime form coalitions to advocate for their technology and to try to collect subsidies. This activity is recognised by Hekkert et al. (2007) as one of the activities that could ultimately gain track and cause the current regime to tip over. Getting involved in these coalitions to contribute valuable industry knowledge and credibility to the coalition could be an opportunity for an airline. The activities of KLM showed that KLM is involved in those collaborations such as the Duurzame luchtvaart tafel and Powerup. Furthermore, a corporation like KLM could advocate for tax regulations and other incentives to stimulate the market and make their fleet more sustainable.

A potential barrier that was recognised for an airline is to be biased. However, based on the interview with E3, all options are still considered in the case of KLM. SAF is already implemented in current operations, but the field for hydrogen and battery-electric is still open. An evident opportunity would be to have a diverse portfolio of projects, including financial support.

6.1.3. Motor C

Lastly, motor C was considered the dominant motor for all three technologies in the innovation system. Motor C is ignited by the guidance of search and drives technical innovation and ultimately the entrepreneurial activities (Hekkert et al., 2007). There is a significant interest in reducing climate impact in the current political and societal landscape. In all industries, primary targets are set to reduce their impact, as well as for aviation. Research is performed to find new energy carriers and fuels, including hydrogen, batteries and SAF. Consequently, resources are available to investigate these new technologies and explore their value, which could be either private equity, subsidies, or incumbent investments.

The knowledge creation that resulted from the guidance was regionally dependent. It was found that in the Netherlands alone, knowledge institutes, such as universities, differ in their focus on research. For instance, at one university more papers were published for battery-electric aviation, while at the other university, more papers emerged for hydrogen. A reason for this difference was not found is this study. However, it is expected that political influence and interest will alternate the view of participant.

It was also found that secondary knowledge creation could be an important factor in the TIS. For example, the current production of SAF is bio-based, meaning that it is produced with feedstock, used oils, or other plant-based materials. However, the resources are scattered, and other uses of feedstock are more preferable. Therefore, a synthetic production method, such as Fisher-Tropsch, would be more suitable. However, for synthetic production, hydrogen is needed, primarily green hydrogen. Therefore, research on green hydrogen production and new storage methods should emerge to shape expectations and stimulate entrepreneurial activities in the coming years. The same applies to battery energy density, although technological experts doubted the enhancement that can be made.

An opportunity was recognised for an airline to shape or guide research to their interest. Again, an airline should be careful with bias guidance to their interest in the early stage of the technologies. Another opportunity is to support the knowledge creation with the profound knowledge of the aviation industry. New technological standards could be aligned with existing knowledge and technologies to reduce possible transition costs for an airline but also for the industry.

In the same opportunity to contribute to knowledge creation a barrier was recognised. The aviation industry's reputation heavily relies on safety and credibility. Because one accident or activity could alter the reputation, innovative or research activities can be seen as high risk. Because innovation requires some trial and error (Schilling, 2019), airlines are reluctant on risky project and want to get involved in trials or perform activities when safety is guaranteed. However, the test environment available is rather low, making it difficult for airlines to get involved in projects without risking reputation.

6.1.4. Additional finding

In this study it came forward that entrepreneurial activities were also used to create knowledge. Which is the opposite of the arrow presented in the model of Hekkert et al. (2007). Although these activities expose entrepreneurs to risk, it was found that one of the reasons to undertake this activities was to create knowledge. This is in line with Hekkert et al. (2007) that explained entrepreneurial activities contribute to knowledge creations and increase the learning curve of an innovation. Therefore, a two-way connection in the model could be considered based on the findings of this study.

6.2. Transition towards sustainable aviation

What	When	Market
SAF	Now	Current market
Battery-electric	This decade	New market
Hydrogen	2040-2050	Current market

Figure 6.2: Summary of transitions with SAF, hydrogen, and battery-electric

The interviews revealed that all participants believed the aviation industry needs to change. The general expectation was a mixture of SAF, hydrogen, and battery-electric aviation rather than one particular solution. Battery-electric aviation was found to be inferior in range but relatively superior in efficiency. Most start-ups, who were interested in battery-electric, thought that battery-electric would ultimately occupy the market for flights shorter than 1000 km. However, other industry experts were doubtful, especially technological specialists such as P8. Reflecting on the current aviation industry, battery-electric solutions will likely fail to compete with traditional flights. However, battery-electric flights could create a new market segment for ultrashort flights that would replace car movements or high-speed trains.

Based on the findings, hydrogen seems to be a great solution although non-CO_2 effects are unknown. When hydrogen is combusted, high temperatures cause the formation of nitro oxides and water vapour. Both are considered greenhouse gases, and the effects are unknown (P8). Apart from the application, most barriers emerge on technical feasibility. The production of green hydrogen and storage on the ground, and air, are big technological challenges. It is therefore expected that a breakthrough of hydrogen as a fuel will not emerge in the coming decade for commercial passenger flights.

SAF is already used in the current industry; however, the feasibility for using SAF only is questionable. Again this relates to the production capacity and the availability of resources. Besides the production capacity, the long-term effects of SAF on traditional aircraft engines are unknown. Based on this study, SAF can be considered a catalyst for sustainable aviation, which would ultimately be replaced by hydrogen or another synthetic fuel.

6.3. Innovation within KLM

6.3.1. Opportunities

The current will to be the front-runner in sustainable aviation is an opportunity recognised. Given this will, it was observed that KLM is formulating a new strategy for innovation. By openly communicating the will to be sustainable and setting a strategy throughout the organisation, employees are empowered with the tools to make decisions that are coherent with the strategy (Gupta, 2011). Moreover, there is a strong culture of pioneering in the company. Besides the interviewees, many employees of KLM that I met during the internship communicated that KLM is a pioneer in the industry. This strong cultural belief can be seen as a stepping stone to explore new technologies.

Aviation is a highly regulated and complex industry. KLM possess much tacit knowledge for operating an aircraft and delivering transportation services. The key of it's value is the transport of passengers and cargo. Because the core value and competency of KLM lays in the transport rather than the technology itself, the transformation towards sustainability can be facilitated while maintaining it's core value and without changing their capabilities. Nevertheless, the macro-study of this study revealed that new technologies could ask for other business models because of the technical capabilities of the new technologies. To explore new configurations of business models, KLM could assign autonomous teams to explore possible configurations.

The last opportunity recognised in the results of this study was diversification. Interviews revealed that battery-electric aircraft could open up a new market opportunity for ultra-short regional flights. Ultra-short flights contrast with KLM's current market proposition, which is more oriented toward long-haul flights. However, this could be an opportunity to diversify the operations of an airline. Palich et al. (2000) showed that moderate diversification of large firms increases performance. Diversification was recognised as an opportunity because, given the results in this thesis, battery-electric flights are most likely to become the first of three technologies that will emerge in a new market. Additionally, opportunities for the E&M department of KLM emerge for new maintenance programs, which are already pursuit in the company. Additionally, an early entry in these markets could also increase the knowledge and learning curve on the new technologies for KLM which can be translated in the corporate strategy for future aviation.

6.3.2. Barriers

In the micro-level analysis at KLM, barriers were found in the organisation for innovation. An airline is an operational-intensive business. The operations are highly efficient; therefore, the organisational structure was also recognised as mechanical, formalised, and standardised (Schilling, 2019). A secondary reason for this structure is the highly regulated nature of safety and reliability in aviation. Currently, the priority of employees are with daily operations. The low priority for innovation could be a barrier in the transition. A clear communicated strategy for innovation and the desire to transition from executive level is key to shift the priority for the future.

Another barrier in the transition towards future aviation is the brand reputation of KLM. The protection of brand reputation is key in aviation as this result in returning customers. However, new technologies mostly start inferior compared to the old technology. Because of the inferiority, customers could experience the service below standard. To protect brand reputation, incumbent actors, such as KLM, show reluctant behaviour to adopt radical changes in technology to protect their high standards. Consequently, new entrants in the TIS, who do not have to protect their brand, can develop their product in a high pace and disrupt the market when the technology meet customers *functional threshold* and *net utility thresholds* (Adner, 2002).
A third barrier was the reliance of partners. KLM is a service-providing entity and therefore relies on partners such as OEMs. For KLM to operate sustainable aviation, the infrastructure should be available, as well as the equipment needed. Because of this reliance, the only major act that KLM can do is to support battery, hydrogen, and SAF initiatives and raise awareness. Support can be either be in the form of knowledge or capital. Because KLM is currently being monitored by the Dutch government, capital support is minimal. Because capital support is seen as the most meaningful statement, the disability of financial support can be seen as barrier in the transition.
A last barrier for KLM is the image of the polluting image of aviation. Despite the will of KLM to become sustainable, every announcement and raise in awareness of the climate is mostly perceived as a form of green washing. The public opinion therefore obstructs the ability to openly support initiatives.

6.4. What can be learned from other transitions?

The most recent example of a disruptive transition is the automotive industry's transition from combustion engines to electric vehicles. Initially, electric vehicles were technically inferior to traditional combustion engines (van Bree et al., 2010). However, the pressure from the landscape level on air quality and climate impact introduced policies favouring electric vehicles' use. Because these vehicles were still inferior, hybrid cars entered the market. These cars partly benefited policy measures but were technically comparable to conventional cars (van Bree et al., 2010). Policy incentives included less tax for electric and hybrid cars. A similar transition could be reflected on the results of this thesis. P1 recognised similarities with the automotive industry.
A transition phase could be recognised in the obligatory blend mandate for SAF. Although SAF is currently more expensive, subsidies or tax advantages could lower the price compared to jet fuel, ultimately making it financially more attractive and increasing demand, leading to an increased supply rate. However, a significant obstacle in the process is the rare availability of the resources needed, which did not apply to electric cars.

What could be learned from other transitions is that new technologies could rise fast when the *functional threshold* and *net utility thresholds* become comparable with the traditional industry (Adner, 2002; Lucas & Goh, 2009). Given the desire of the larger public to switch to sustainable alternatives, it is likely that the threshold of customers to use green alternatives is lower. In other words, I think it is likely that customers will change to sustainable alternatives despite hydrogen and battery planes are inferior in terms of range and speed. However, the current stage of both technologies is to early to emerge out of a sudden.

Nevertheless, KLM displayed that they want to be the front runner in sustainable aviation. To do so, supporting new technologies is key. It was recognised that KLM is somewhat reluctant in announcing the support of initiatives due to the risk that comes with testing new technologies. Testing entails risk and could damage brand reputation. Protecting brand reputation could therefore be seen as an obstacle in their transition. An example of a company who failed to be the front runner is Hasselblad. Hasselblad, an analogue photo camera company who strictly protected their high quality photos, became one of the core rigidity to learn and adapt the emerging digital camera market. Hasselblad overcame their rigidity, and survived the transition, through acquisitions and mergers (Sandström et al., 2009).

Lucas and Goh (2009) describes two extensions for firm transition. First, the *struggle for change*. The core idea is that there should be a balance between core rigidities and dynamic capabilities, Figure 6.3. The key message in literature is that vision, strategy, and the communication of both are essential in the balance. Consequently, (senior) managers must teach subordinates to think with a vision and strategy for the future, leading to thoughtful decision-making. Again, a learning case can be found in the photography industry. In the case of Kodak, there was a significant belief and will in upper management to change to digital cameras. However, middle management was rigid and failed to communicate and translate the vision among employees. Additionally, Kodak tried to create a separate business unit for digital cameras; however, the business unit was still too attached to the mother company, which lowered the vigour (Lucas & Goh, 2009).

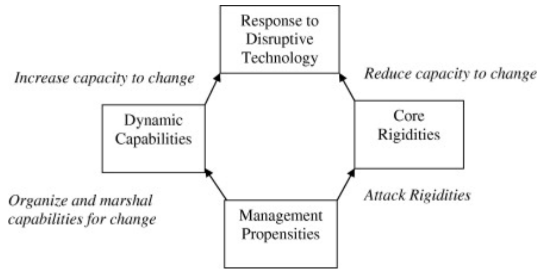

Figure 6.3: Balance between core rigidities and dynamic capabilities to act on disruptive technologies (Lucas & Goh, 2009)

A second extension was the *organisational culture*. There needs to be an open culture for change. Lucas and Goh (2009) recognised that bureaucratic is associated with slow response and employees who value security over risk-taking. Consequently, this leads to inertia of the firm which impedes disruptive change. In case of Kodak, innovation was suppressed because failures would cost the company a lot of revenue. This culture demotivated employees to take risk and look toward the future. Moreover, management kept underestimating the market of digital cameras and found out too late.

Reflecting this on the findings on micro level at KLM, the transformation office takes steps in the right direction by educating and communicating the need for innovation throughout the business entities of KLM. It is also important that the board of KLM clearly advocate for innovation and the vision to pioneer sustainable aviation. By doing so, middle management should also stimulate employees to be brave and suggest improvements or exploit there expertise to formulate ideas that could fit in the future of aviation.

Another lesson that can be learned from Kodak is to assign a team separated from the mother business to investigate new opportunities. A mistake that needs to be avoided is to fail separating the team completely. As in the Kodak case, an attempt was made but team members still were too busy with operational task. At KLM an attempt is recognised to separate some people from the operational tasks but this was limited to a handful of people. Another interesting finding was in particular for E3. E3 is assigned as program manager zero-emission aviation although this can be recognised as a good attempt to starting a separated and autonomous team, it was interesting that E3 does not directly report to the board. Reflecting the situation on the team formation and reporting lines from Schilling (2019), E3 remains in the category of a functional team and is still part of a functional department. This reporting structure interferes with the vigour of the team and the separation from the operational part is questionable and could lead similar missed opportunities as in the case of Kodak. An autonomous team as suggested by Schilling (2019) would be more suitable as this type reports to the CEO and is power to make its own decisions.

7

Conclusion

This study started with the statement: *becoming green while flying blue*. Within the industry many initiatives and ideas are active to plan for the future. Considering the three main technologies that are considered SAF and battery electric seem to emerge in the short future. For hydrogen technical challenges need to be overcome and is therefore not expected in the near future.

The study revealed that the TIS for sustainable is present but the motors of the TIS are obstructed. Main barriers were for the legitimisation and lobby. The biggest barrier is the high safety standards within the industry which impedes testing and developing sustainable technologies. This barrier hampers market formation and create uncertainty in which direction the transition should develop which could be an explanation for reluctance in resource allocation. Another cause for the obstructed legitimisation was found in the micro environment. KLM, and also other airlines, depend on their brand reputation. Consequently, the risk of trying disruptive propulsion technologies is avoided as this could significantly impact the future of the company. One of the solutions would be closed test environments to test new technologies and generate data for these technologies of course with non-human trials. The interview with a government manager revealed that options are considered.

It was also found that the complexity of the industry is a significant barrier to the transition. Many stakeholders are involved in the industry with different perspectives and stakes. Not only are there many stakeholders, but they are also highly dependent on each other. Therefore, transforming towards a sustainable future depends on collaboration which makes the transition politically complicated due to the different stakes of each party. Additionally, the transition requires different regions on a world scale to transition in parallel because of the logistics and refuelling of sustainable aeroplanes in the transport network, which increases the complexity of change.

A last barrier that emerged during my thesis was the negative image of aviation. Although the aviation industry accounts for 2.1% of greenhouse gas emissions (Ge et al., 2022), the general public associate aviation as one of the biggest causes of climate change. Consequently, well-meant initiatives are negatively received by some population groups and are judged as forms of green washing. This causes a negative influence on brand reputation and makes incumbent actors reluctant to announce cooperation and steps towards sustainable aviation. This barrier is, therefore also associated with the inhibition of innovation motors in the TIS.

The barriers in the industry make it hard for a single actor to be a front-runner in the industry. Nevertheless, KLM people that I met during my thesis advocate the will to take a pioneering role in becoming sustainable in aviation. Based on the findings, a pioneer in sustainable aviation should have several characteristics. First, a pioneer needs a clear strategy advocated throughout all company layers by the board. Secondly, a pioneer should educate employees on innovation. Thirdly, be a spokesman for the industry, sharing concerns, breakthroughs, and opportunities to reframe the negative image that emerges in public. Lastly, a pioneer should show total commitment and priority in projects for sustainable aviation.

During the micro study goods steps were recognised in KLM such as formulating a new innovation strategy, educating people to innovate, and assigning teams, separated from priority of daily operations, to investigate sustainable aviation. Points of improvement are recognised in the commitment and priority of sustainability and be a spokesman for the transition of the industry. These two themes could be improved by increasing the autonomy and decision power of sustainability teams, have a clear statement from the board to prioritise the future of aviation, and to take a more active role in panels on several media platforms to reframe the public image and show milestones that are accomplished.

For aviation a long road lays ahead to become green. Both technical challenges as well as the challenges discussed in this thesis make the transition complex and time consuming. The industry is at the beginning of its transition as it seems that battery-electric flights will become available within this decade, opening up new opportunities and potentially disrupt short-haul flights. Many challenges lay ahead for KLM to implement these new technologies in their current operations. Changing will require a shift in mind set and a focus on the long term future of aviation including reconsideration of business models and how to include new technologies in an early stage to pioneer and show the world what is possible. A clear vision and priority to prepare the organisation for the transition towards sustainable aviation will make it possible to become green while flying blue within the decades to come.

7.1. Discussion

7.1.1. Reflection of the method

The method used was qualitative. I chose this because I had little knowledge of the aviation industry, and qualitative methods were the fastest way to obtain much knowledge quickly. Moreover, the goal was to understand the social challenges of the transition better. As this involves the experience and view of people, a qualitative approach was most suitable. It could be argued that a quantitative analysis of a survey or similar method would also be appropriate for this study. However, my previous experience with surveys was negative, as it is hard to generate a high response rate during a thesis. For that reason, a qualitative approach was chosen.

This study used a macro and micro perspective. This resulted in a broad perspective of the challenges of the transition. Using both perspectives also resulted in a better understanding of why incumbents seem reluctant to change, which can be mostly attributed to the complexity and reliance on a network of actors and regulations.

In hindsight, focusing on micro or macro perspectives would have yielded more specific results. Investigating the micro and macro perspectives of the transition lowered the ability to do in-depth research on one of them. Consequently, the results of this study are rather general. If I had to perform this study again, I would focus solely on the microenvironment. With more than 100 years of experience, KLM has a lot of industry knowledge and understands the dynamic of many processes and why some things are so complicated. Creating a deeper understanding of why things are how they are could have resulted in more specific barriers that airlines encounter in the transition.

7.1.2. Scientific relevance

The core of this research was to investigate the experienced barriers and opportunities for sustainable aviation technologies from a macro- and micro-level. Technologies included SAF, hydrogen, and battery-electric solutions. Because barriers and opportunities emerge on the macro- and micro-level, both perspectives were considered. The exploratory phase at the beginning of this study revealed that although much research is performed on the technical feasibility of all three technologies, no literature was found on how incumbents should act or which role they could play in the transition towards sustainable aviation. This study delivered a new insight on macro- and micro-level within the literature scope of the seven functions of a TIS and strategic innovation management.

Several theoretical models were considered for technological transition and innovation to make a solid base for scientific contribution. These considerations resulted in a conceptual model with a macro-level, the technological innovation system and the seven functions, and a micro-level that was researched in the form of a case study at KLM.

Reflection of the used theory

The research revealed the beliefs and motivations of industry experts. The beliefs and motivations were categorised in the seven function models to see which factors contributed to the functions in the conceptual model. Although the seven-function model states that the three motors drive entrepreneurial activities, an intrinsic motivation to change the industry comes from sustainable awareness. The intrinsic or sustainable driver could be an additional factor in sustainable transitions.

Additionally, the seven-function model fails to describe the influence of sustainability as a driver for innovation. Especially in the current time frame of society, the influence seems primarily based on the results of this study. It would be interesting to investigate the influence of the sustainability trend on the model.

Another interesting insight was the bilateral influence between *entrepreneurial activities* and *knowledge creation*. In the model, the arrow is unilateral from *knowledge creation* towards *entrepreneurial activities*. One of the motivations to start entrepreneurial activities among some participants was to contribute/accelerate knowledge creation for the transition. This motivation was derived from sustainable beliefs.

7.2. Limitations

During the study, selecting a varied participant group was tried to create a balanced data set with several perspectives. Several actors were included in the study, such as start-ups, governments, consultants and other industry-related experts. The only view absent in this study is from the fuel suppliers. Additionally, start-up interviewees in this industry only included participants focused on battery-electric aviation. Including fuel suppliers and hydrogen, start-ups could have resulted in additional data.

Data from the external participants of this study was not verified with a member check. There was no specific reason why the check was not performed. A member check would have increased the quality and validity of the data. Nevertheless, based on the data saturation and the contradicting views of the participants in the data set, it was assumed that the data did not contain significant errors or was unbalanced.

A last limitation that was found was the timing of this research. Battery-electric and hydrogen are very premature technologies and far from industry adaption. It is, therefore, questionable if the results of this study will be applicable in the future and give a valuable overview of the barriers and opportunities for an incumbent airline. However, the results could be considered to shape expectations and be part of the transition.

7.3. Recommendation

7.3.1. Recommendation for policy makers

This research found that the transition towards sustainable aviation has barriers that must be overcome. The main barriers in the functions were legitimising the three technologies for sustainable aviation and market formation. Similar to many transitions, the new technologies are inferior, more expensive, and must be optimised to the existing infrastructure.

Although the stage of all three technologies is relatively early, it is recommended that policymakers actively prepare to facilitate the transition. Collaboration between policymakers and industry actors is vital to overcoming legislative barriers. Policymakers should especially look into the legislation of storage of hydrogen but also permits for on-site energy productions at airports to facilitate the transformation of the infrastructure of sustainable technologies.

Furthermore, stimulating measurements should be installed to lower actors' barriers to adopting clean technologies. An example is to make new flight slots available for sustainable aircraft. This is in light of the current flight reduction of Schiphol due to noise pollution. Preliminary results show that sustainable aircraft cause significantly less noise than traditional planes. An incentive to update their fleet to exploit new revenue opportunities is expected to accelerate the transition.
SAF is the most advanced of all three and is currently used by several airlines, such as KLM. Within the market, the biggest obstacle is kick-starting the demand and supply of the market. Policymakers can play an important role in stimulating the market formation of SAF. It is recommended that policymakers stimulate the demand side by installing a higher percentage of a blend mandate to artificially increase the demand side to stimulate suppliers to increase their production and lower production costs.

Lastly, policymakers should *give up military airspace for testing new aviation technologies*. Policymakers can accelerate knowledge creation by facilitating new initiatives and research groups in closed test environments to test ideas. Airspace should be assigned to accelerate the knowledge creation of all three technologies. Another option is to lower safety standards for early-stage technologies. These lower standards should only apply in controlled and low-scale testing environments of basic technological principles.

7.3.2. Recommendations for KLM

The first recommendation is to prioritise innovation. Good steps are taken to educate employees on innovation and that the world of aviation is changing. The board must communicate a clear vision and strategy for prioritising innovation if they want to keep the pioneering character of the company within the industry. The first recommended step is repositioning project/program managers from functional teams towards autonomous teams. By repositioning those teams, the board would give a clear message of understanding the transformation that the company is facing if it wants to pioneer and maintain its market position. Additionally, the repositioning would increase the speed of decisions, and opportunities can be seized in an early stage. The vision and priority must be communicated in all layers of the organisation to create a shift in mindset. However, it could also be a bold statement to the public.

Another recommendation is to be more present in the public about sustainable aviation. Currently, most of the initiatives are kept quiet because of the negative reaction by the public. Opening up about the barriers that are faced and the milestones that are accomplished would be an opportunity to reframe the bad reputation of aviation concerning climate change. This is one of my recommendations because KLM is going in the right direction to tackle the sustainability problem but is hesitant about the public's opinion. However, this recommendation should be combined with the first recommendation to clarify the priority of sustainability.

Lastly, an open mind should be kept. The current stage of the technologies is early, except for SAF. For now, a mix of all three technologies is believed to be the future of aviation. For KLM to remain a global aviation industry leader, an open mind about these three technologies and new undiscovered ones is required.

7.3.3. Recommendations for future studies

A first recommendation would be to repeat similar research in 5 years. Results showed that battery-electric and hydrogen are in a relatively early stage. With the interest of several knowledge institutions and the industry as a whole, the development of technical feasibility will likely increase. Given the growing technical ability, legislation and legitimisation are expected to change, and markets will emerge. Repeating this study could lead to new insights when both functions are more developed.

Another recommendation would be to investigate the influence or role of sustainability on the seven-function model. As discussed earlier, sustainability is a considerable motivation for companies and start-ups to start their entrepreneurial activities. Therefore, future research should investigate if and, if so, where sustainability would fit in the model.
Another theoretical study would investigate the bilateral relation between *entrepreneurial activities* and *knowledge creation*. The current model only highlights the unilateral relation from *knowledge creation* towards *entrepreneurial activities*. However, results show there might also be a relation the other way around.

Lastly, the results showed that some technologies, mainly battery-electric solutions, could lead to a new market with a different revenue model. This thesis suggests conducting future research with a theoretical framework related to *business model innovation* within the aviation industry. Because the aviation industry is complex and highly regulated, it is proposed to perform this research with industry experts to understand the needed changes and implications for the traditional industry.

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A

Informed consent

Informatie duurzaam vliegen interview

Obstakels en kansen voor duurzaamvliegen

Beste meneer/mevrouw,

Fijn dat u tijd wilt maken om aan mijn scriptie bij te dragen. Ik ben op dit moment aan het onderzoeken wat de obstakels en kansen zijn om de transitie te maken naar duurzaam vliegen. Duurzaam, of klimaat neutraal, vliegen is een grote uitdaging. Zowel op technisch als maatschappelijk gebied. Een transitie is daarom complex en staat op dit moment nog relatief in de kinderschoenen. Ik wil in mijn onderzoek vooral de maatschappelijk kant bekijken door te onderzoeken wat de barrières en kansen zijn in de industrie met de focus op waterstof, elektrisch en SAF vliegen. Ik doe dit aan de hand zeven functies binnen een innovatie systeem (Hekkert et al., 2007). De zeven functies zijn:

Entrepreneurial activity	Lobby/government
Guidance of search	Resource allocation
Knowledge sharing	Market (formation)
Expectations	

Het doel van de studie

Het hoofddoel van dit onderzoek is om uw visie in kaart te brengen omtrend de ontwikkeling en transitie naar klimaat neutraal vliegen. Hierbij ga ik kijken welke barrières en kansen naar voren komen binnen de thema's van de zeven functies. De resultaten zal ik binnen KLM bespreken om te kijken hoe hun innovatie activiteiten aansluiten bij mijn bevindingen.

Wat betekend uw deelname aan de studie?

De interviews zijn bedoeld om de mening en ervaringen van experts in de industrie te verzamelen, waaronder die van u. U heeft voor dit interview daarom geen voorkennis nodig. In totaal zal er ongeveer 45 minuten worden ingepland om er zeker van te zijn dat er genoeg tijd is, maar meestal zijn we eerder klaar.

Het is belangrijk om te vermelden dat u op elk moment uw deelname aan dit onderzoek kunt beëindigen zonder een reden op te geven. U kunt ten allen tijden contact opnemen met de mij of de supervisor van mijn scriptie, contactgegevens vindt u onderaan deze brief.

Uw bijdrage zal uw persoonlijke mening en ervaring bevatten en zal daarom worden geanonimiseerd. Van het interview zal een audio-opname worden gemaakt, die na transcriptie zal worden verwijderd. De resultaten worden alleen gebruikt voor onderzoeksdoeleinde. Mocht u nog vragen hebben of contact willen hebben dan kunt u onderstaande personen bereiken per email en telefoon.

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B

Interview guide

Warming up

Klein praatje met de participant over wie ze zijn en wat ze doen. Hierbij afsluiten met het bespreken dat het interview zal worden opgenomen en het doel van het interview en de studie uitleggen.

Binnen de scoop blijven van brandstoffen en niet te veel uitwijken naar AAM of ander soort vliegtuigen.

- Leeftijd
- Ervaringen binnen de luchtvaart industrie
  - In welke bedrijven heeft u gewerkt voor de luchtvaart?

Hoofd onderdelen

Toekomst van de luchtvaart

- Welke ontwikkelingen voor schone technologieën spelen er binnen de luchtvaart?
- Welke bedrijven/instanties lopen voorop in de ontwikkeling van uitstootvrij vliegen?
- Welke rol speelt de overheid/EU in de transitie naar duurzaam vliegen?
  - Zijn er duidelijke doelen gesteld voor duurzaam vliegen vanuit Den Haag/EU? Zo ja, hoe zien die er uit?
  - Is daar bij ook innovatie budget? Zo ja, waar kan dat allemaal voor gebruikt worden?
- Hoe is de regelgeving omtrend het gebruik van nieuwe technologieen binnen de luchtvaart?
  - Zijn er tekortkomingen aan de huidige regelgeving? Zo ja, welke?
- Waar wordt op dit moment het meeste onderzoek naar gedaan? en waarom?
- Hoe ziet volgens u de toekomst eruit omtrend CO2 vrij vliegen?

Markt vorming

- Is er al een markt voor schone vliegtuigen? Zo ja, hoe ziet de markt eruit voor clean aviation?
- Is er samenwerking tussen verschillende partijen? Zo ja, hoe zien die samenwerkingen eruit?
- Wordt er gelobbyd door partijen?
  - Welke partijen en bij wie?
  - Voor wat wordt er gelobbyd?

Energie dragers

Geven van context om gesprek binnen de scope te houden. In literatuur en het nieuws drie hoofd thema's als het gaat om schoon vliegen: SAF, waterstof, en elektrisch.

- Welk van deze energie dragers is volgens u het meest belovend en waarom?
- Wat moet er worden veranderd om schone brandstof commercieel te maken?

- Waarom zijn de andere energiedragers minder geschikt in uw ogen?
- Wordt er naar een specifieke brandstof meer onderzoek gedaan dan naar andere? Zo ja, welke en waarom?
- Worden er resources gemobiliseerd voor de ontwikkeling van deze nieuwe technieken?
  - Zo ja, wat voor soort resources en hoe?

Laatste opmerkingen

Zijn er nog op of aanmerkingen of iets wat niet besproken is?