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Analysis of the Dutch Mission-oriented Innovation System for sustainable aviation

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Abstract

Modern society faces an increasing number of societal challenges and Mission-oriented Innovation Policy (MIP) has been proposed as a potentially effective method to bring about transformative change (Wanzenböck et al., 2020; Diercks et al., 2019).

The Mission-oriented Innovation System (MIS) framework is applied in this thesis on the Dutch mission for sustainable aviation. This case is selected, as this is one of the most global sectors in which many actors, networks, and institutions are involved both on a national and international level. The Dutch government wants to reduce carbon emissions of its aviation sector and has published the Civil Policy Memorandum. This policy memorandum delineates a safe, connected, and sustainable growth of the aviation sector in the Netherlands towards 2050 (Rijksoverheid, 2020a). The targets and solutions to achieve carbon reduction are outlined in this document. To analyze this mission, the five steps of the adjusted structural-functional approach for the MIS have been followed. Literature on how MIP relates to its geographical scope and ensuing coordination problems is currently underdeveloped (Wanzenböck & Frenken, 2020). This thesis aims to further substantiate MIS components in an international context. Improved understanding and conceptualization of the geographical context on a supranational and global level will guide analysts in their search for interactions. Similarly, it would increase context-awareness amongst policymakers in which the direction the mission is developing (Bergek et al., 2015).

In total 32 semi-structured interviews were conducted among many actors contributing to the mission. A thematic analysis was conducted to analyze the different system functions. The data gathered from the interviews resulted in many identified barriers from the weakly fulfilled system functions. From these systemic barriers, three networks were identified with the most pressing systemic problems. These are about the governance, as there is a missing central steering of the mission, insufficient upscaling support for Sustainable Aviation Fuels (SAFs), and a missing long-term policy framework for technological innovations. To address these barriers, many mission governance actions were identified. However, most of these actions are planned and therefore the barriers are not adequately addressed yet at this moment. This thesis provides many recommended 'focus points' and interventions to take into account.

Table of contents

Appendices

List of figures

List of tables

List of abbreviations

Abbreviation	Meaning
ATC	Air Traffic Controller
ATAG	Air Transport Action Group
ATM	Air Traffic Management
CO_2	Carbon dioxide
CORSIA	Carbon Off-set and Reduction Scheme for International Aviation
DMI	Dutch Mobility Innovations
EASA	European Union Aviation Safety Agency
EC	European Commission
EU	European Union
EU-ETS	EU Emissions Trading System
GIS	Global Innovation System
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IPCC	Intergovernmental Panel on Climate Change
KiM	*'Kennisinstituut voor Mobiliteitsbeleid'* (Netherlands Institute for Transport Policy Analysis)
LTAG	Long-Term Aspirational Goal
MGA	Mission Governance Actions
MIP	Mission-oriented Innovation Policy
MIS	Mission-oriented Innovation System
Ministry I&WM	Ministry of Infrastructure & Water Management
MoU	Memorandum of Understanding
NAG	Netherlands Aerospace Group
NDC	Nationally Determined Contributions
NGO	Non-governmental organization
NIS	National Innovation System
OEM	Original Equipment Manufacturer
R&D	Research & Development
RDM	*Subsidieregeling R&D mobiliteitssectoren*
RED	Renewable Energy Directive
RIS	Regional Innovation System
SAA	Sustainable Aviation Agreement
SAF	Sustainable Aviation Fuel
SAP	State Actions Plans
SAT	Sustainable Aviation Table
SESAR	Single European Sky Air Traffic Management Research
SF	System Function
SIS	Sectoral Innovation System

SME	Small and medium enterprises
SRL	Social Readiness Level
TIS	Technological Innovation System
TRL	Technology Readiness Level
TSH	TopSector Hightech
UN	United Nations
WoS	Web of Science

1. Introduction

Modern society faces an increasing number of major social, environmental, and economic challenges (Mazzucato, 2018). Sometimes referred to as 'grand challenges', these include environmental threats such as climate change, affordable health, and well-being concerns. As Mazzucato (2018) states *"these problems are 'wicked' in the sense that they are complex, systemic, interconnected, and urgent, requiring insights from many perspectives"* (p. 203). Fortunately, governments are increasingly concerned with tackling grand challenges and implementing sustainable development goals. Innovation plays an important role in steering the rate and direction to solve societal challenges (Janssen et al., 2020). Systems perspectives such as national-, regional- and technological-specific innovation systems have been introduced over the past decades (Hekkert et al., 2007). These perspectives are focused on market and system failures but are unable to address transformation failures (Hekkert et al., 2020). Therefore, additional policies are required to transform socio-technological systems of production and consumption besides current policies aimed at encouraging technological innovation (Mowery et al., 2010). Transformative innovation policy legitimizes government intervention aimed at influencing the directionality of innovation systems towards societal problems (Hekkert et al., 2020).

Societal, challenge-led missions appear more complex and unstructured compared to conventional technology-led missions (Wanzenböck et al., 2020). A lack of understanding of the innovation system dynamics in terms of formulation, pursuit, and completion of a mission, poses an immense challenge to policy makers on how to compose and assess effective policy (Hekkert et al., 2020). Consequently, scholars have signaled the arrival of a 'third-generation' innovation policy aimed at overcoming societal challenges (Haddad et al., 2019). Mission-oriented Innovation Policy (MIP) has been proposed as a potentially effective method (Wanzenböck et al., 2020; Diercks et al., 2019). MIP is regarded as an innovation policy with the explicit aim to bring about transformative change. MIP aims to achieve specific objectives, drives innovation across multiple sectors, and involves both public and private actors (Mazzucato, 2018). Transformative missions require substantial governance and also the involvement of other stakeholders, besides governments (Larrue, 2021). Therefore, the measures that aim to achieve the mission's goal are referred to as '*mission governance actions*' (MGAs) instead of MIP (Wesseling & Meijerhof, 2021).

To design and implement MGAs, a framework is necessary that maps and evaluates innovation dynamics, contributes to completing a societal mission, and designs appropriate intervention strategies (Hekkert et al., 2020). The Mission-oriented Innovation System (MIS) is a promising framework within systems perspective literature. MIS emerged recently and is a novel theory under development. The advantage of MIS is its ability to analyze grand societal challenges and specifically, the directionality of missions (Hekkert et al., 2020). Hekkert et al. (2020) define an MIS as "*the network of agents and set of institutions that contribute to the development and diffusion of innovative solutions with the aim to define, pursue and complete a societal mission*" (p. 77). An MIS identifies the underlying barriers inhibiting the diffusion and development of both technological and social innovative solutions within the mission and recommends MGAs to achieve faster mission success (Hekkert et al., 2020; Wesseling & Meijerhof, 2021).

Till now the MIS concept is only applied once earlier in a working paper about the Dutch mission for sustainable shipping (Wesseling & Meijerhof, 2021). Thus, there is an urgent need to conduct more deductive research to further develop the MIS framework. The MIP literature states that each mission is unique and that missions vary along different dimensions (Janssen et al., 2020; Larrue, 2021; Mazzucato, 2018). Therefore, the applicability of the MIS framework needs to be applied and tested on different types of missions to build theory on how different missions impact the MIS dynamics (Wesseling & Meijerhof, 2021). One of the dimensions a mission can differ is the geographical span and scope, resulting in ensuing coordination problems (Wanzenböck & Frenken, 2020). The mission arena has a central directing and system building role, however there is a lack of empirical evidence on how societal problems are related to their geographical context (Wanzenböck & Frenken, 2020). Beyond the geographical borders of the MIS other regional, national, sectoral, technological, and global mission components are mobilized and driven by other structural components influenced by large entities to achieve the mission's targets (Fuenfschilling & Binz, 2018). Improved understanding and conceptualization of the geographical context on a supranational and global level will guide analysts in their search for interactions, similarly it would increase context-awareness amongst policymakers in which the direction the mission is developing (Bergek et al., 2015).

Therefore, this thesis aims to make two contributions to the body of MIP literature. First, this thesis contributes to the literature by evaluating whether the planned or recently implemented MGAs adequately target the mission's systemic barriers. This is done by providing formative recommendations for MGAs, meaning policy can be improved to eliminate or reduce the adverse effects of these barriers (Wesseling & Meijerhof, 2021). Secondly, this thesis aims to empirically contribute to understanding the challenges that are encountered when mobilizing the structures of an MIS in a strong international context and a large geographical span. These context structures are characterized by structural components influenced by large supranational entities and will be conceptualized building on the work of Wesseling & Meijerhof (2021) and Fuenfschilling and Binz (2018).

The case discussed in this thesis is the Dutch mission for sustainable aviation. Aviation is one of the most global sectors in which many actors, networks, and institutions are involved both national and international in the problem framing and the development of solutions (ICAO, 2018). Air transportation connects people and economies around the globe and is a key element of our society. Aviation has grown rapidly over the past decades and contributes to increased connectivity and economic growth (Gössling & Humpe, 2020). Consequently, carbon emissions resulting from the usage of fossil fuels have also increased (Lee et al., 2020). Technological advances have reduced relative carbon emissions but cannot compensate for the overall growth. The growth of the number of flights has caused an increase in noise and emissions, which have a negative impact on ecosystems and the well-being of humans around the world (Gössling & Humpe, 2020). In 2018, aviation was responsible for about 3% of the total anthropogenic CO_2 emissions, while contributing 3.5% to global warming because of increased radiative forcing by non-CO_2 emissions high in the atmosphere (Lee et al., 2020). To avoid the catastrophic effects of climate change global average temperature rise must be limited between 1.5° and 2° Celsius (International Panel on Climate Change [IPCC], 2018).

The *Luchtvaartnota* (Dutch Civil Aviation Policy Memorandum) delineates a safe, connected, and sustainable growth of the aviation sector in the Netherlands towards 2050 (Rijksoverheid, 2020a). The targets and solutions to achieve carbon reduction are outlined in this document. The mission's targets to reduce CO_2 emissions of international flights departing from the Netherlands are a reduction to 2005 levels in 2030, in 2050 a 50% gross reduction compared to 2005 levels and in 2070 the target is zero emissions (Rijksoverheid, 2020a). The scope of this thesis is defined by this mission, which started in 2018 when the Sustainable Aviation Agreement (SAA) was signed. Domestic aviation is excluded from the scope of this thesis, due to its relatively small contribution to the total amount of emissions (Rijksoverheid, 2020a). A detailed description of the case is found in Appendix I. The following research question is proposed:

"Do the ongoing or planned mission governance actions in support of the Dutch MIS to reduce CO_2 in international aviation adequately target the barriers of that MIS?"

To answer this research question, sub-questions are categorized based on the different analytical steps in the MIS framework (Wesseling & Meijerhof, 2021). This allows a more systematic approach to identify the systemic barriers and results in recommendations for MGAs. Besides, there are sub-questions added concerning the contribution to the international context. This thesis is structured by an introduction, theory, methodology, results, discussion, and conclusion format.

Sub questions

Problem-solutions diagnosis

1) How are different societal problems included and prioritized in the mission formulation?
2) What technological and social solutions are relevant to the mission?

Structural systems analysis

3) What actors, institutions, networks are active in the MIS to support the mission's solution including the phase-out of harmful practices and technologies?
    a) How are these actors involved in the mission formulation and its continued governance?
    b) How are these actors involved in mobilizing other MIS components in pursuit of the mission?
    c) How do the Mission Governance Actions (MGAs) of the mission arena align with existing institutional structures related to the mission?
4) What are the international structures around the focal MIS?
5) What MGAs are currently implemented?
    a) How do MGAs interact with the identified international structure?

System functions analysis

6) What are weak fulfilled system functions and systemic barriers inhibiting swift mission success?

Systemic barrier analysis

7) What is the cause of the systemic barriers stemming from the weak fulfilled functions?
8) How do the systemic barriers interact with the identified international structure of the MIS?

Evaluation of governance actions

9) Do the MGAs address the identified systemic barriers?
10) What are possible MGA recommendations to improve mission policy?

2. Theory

2.1. Innovation Systems

According to Carlsson et al. (2002), a system is *"a set of interrelated components working toward a common objective"* (p. 234). Systems are made up of components, the relationships among them, and their characteristics or attributes (Carlsson et al., 2002). Components can be actors and institutions which are for instance individuals, businesses, banks, universities, research institutes, and public policy agencies. Components can also be physical such as medicine or technological devices and they can be divided among institutions into formal (e.g. constitutional- and regulatory law) and informal (e.g. traditions and social norms) (Carlsson et al., 2002; North, 1991). Relationships are the interactions among these components, depending upon the properties and behavior of at least one or more of the components. The number of interactions in the system determines, by definition, how dynamic it is. However, even highly dynamic systems need to evolve in the right direction to survive. Lastly, the attributes are defined as the properties of the components themselves and the interactions among them. The properties and behavior of each component affect the system as a whole (Carlsson et al., 2002).

The first generation of innovation policy was aimed at fixing market failures such as improving research & development at private firms (Hekkert et al., 2020). From the 90s onwards this shifted more towards innovation for economic growth (Schot & Steinmueller, 2018). This second generation of innovation policy was aimed at strengthening national innovation networks and fixing failures in national innovation systems (Hekkert et al., 2020). Over the last decades, several innovation systems were developed (see Figure 1). The Regional Innovation System (RIS) focuses on a specific region, while a National Innovation System (NIS) is geographically bounded to the borders of a country (Chung, 2002). The Sectoral Innovation System (SIS) focuses on a specific sector (Malerba, 2002). A Technological Innovation System (TIS) focuses on a specific technology while not being limited geographically or to a specific sector (Hekkert et al., 2007).

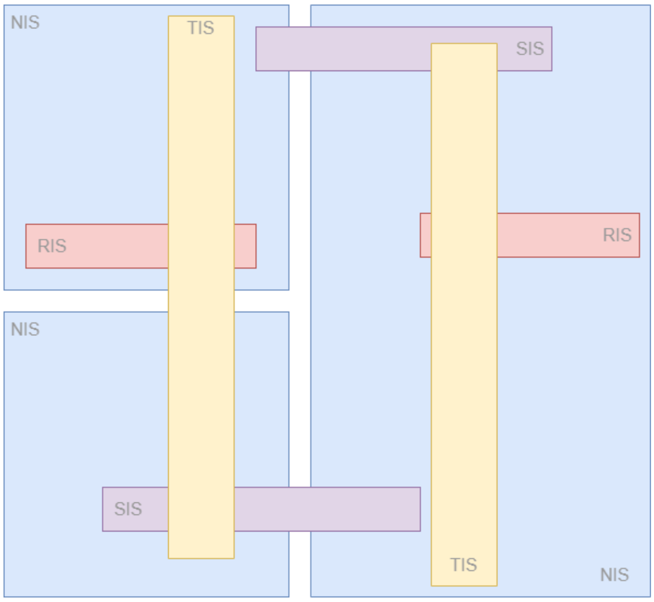

Figure 1, Different innovation systems. Adapted from "Development and application of the Mission-oriented Innovation Systems (MIS) approach (working paper)," by J.H. Wesseling and N. Meijerhof, 2021, p. 9, Copernicus Institute of Sustainable Development, Utrecht University.

2.2. Mission-oriented Innovation Policy (MIP)

Current innovation systems are unable to assess an innovation system revolving around a certain mission. For that reason, scholars have identified a 'third-generation' innovation policy aiming to overcome societal challenges labeled as *challenge-led, mission-oriented innovation policy* (MIP) (Haddad et al., 2019; Wanzenböck et al., 2020). In addition to market and system failures, this policy legitimizes government intervention aimed at influencing the directionality of innovation systems to address societal challenges (Hekkert et al., 2020). MIP distinguishes itself through an explicit focus on providing directionality through ambitious, actionable, measurable, and time-bound goals (Wesseling & Meijerhof, 2021). MIP is perceived as *"a directional policy that starts from the perspective of a societal problem and focuses on the formulation and implementation of a goal-oriented strategy by acknowledging the degree of wickedness of the underlying challenge, and the active role of policy in ensuring coordinated action and legitimacy of both problems and innovative solutions across multiple actors"* (Wanzenböck et al., 2020, p. 3). Besides policies initiated by governments, also stakeholders are involved in actions for the governance of transformative missions (Larrue, 2021). Therefore, the measures that aim to achieve the mission's goal are referred to as '*mission governance actions*' (MGAs) instead of MIP (Wesseling & Meijerhof, 2021). Existing socio-technical and innovation systems are unable to deal with the implications of these challenges. Therefore, a clear operational and systematic approach taking a systems perspective is required (Hekkert et al., 2020).

2.3. Mission-oriented Innovation System (MIS)

The aforementioned innovation systems cannot assess the impact of MIP as they are too open-ended concerning transitions, they miss a clear operational approach, or they lack a sufficiently detailed perspective of embedded systems (Wesseling & Meijerhof, 2021). Wesseling & Meijerhof (2021) have identified conceptual challenges of MIP concerning the wickedness, temporality, embeddedness, and directionality of missions (see Table 1). The mission-oriented innovation system (MIS) framework is a novel theory capable to assess the impact of MIP. Hekkert et al. (2020) define an MIS as *"the network of agents and set of institutions that contribute to the development and diffusion of innovative solutions with the aim to define, pursue and complete a societal mission*" (p. 77). The concept of a societal challenge-based mission is defined as "*an urgent strategic goal that requires transformative systems change directed towards overcoming a wicked societal problem*" (Hekkert et al., 2020, p. 76). Within the MIS both technological and social innovative solutions and their interactions are included (Wanzenböck et al., 2020). Social innovations are described by Rehfeld et al. (2015) as "*novel combinations of ideas and distinct forms of collaboration that transcend established institutional contexts"* (p. 1). The MIS mobilizes existing actors, networks, institutions, and materiality and realigns the innovation system structures to establish a well-functioning system that is directed by a concrete, actionable, and broadly supported mission (Wesseling & Meijerhof, 2021)

Table 1, An overview of the differences between TIS and MIS from "Development and application of the Mission-oriented Innovation Systems (MIS) approach (working paper)" by J.H. Wesseling and N. Meijerhof, 2021, p. 6, Copernicus Institute of Sustainable Development, Utrecht University.

Dimension	**TIS**	**MIS**
Analytical focus	Focus on one technology.	Focus on one mission with its underlying sets of technologically and socially innovative solutions and phase-out of existing practices and technologies.
Wickedness	Involves uncertainty, complexity, and contestation within the scope of a single solution, involving competition between technological designs. Overlooks regime resistance.	Involves uncertainty, complexity, and contestation in terms of a) the problem definition and prioritization, and b) the solution scope in which sets of different types of solutions interact. Contestation translates into the risk of capture by the regime.
Temporality and embeddedness	Technologies emerge, mature and phase-out, in one or more sectoral contexts.	Missions are formulated and completed or discontinued. They emerge around societal problems and aim to mobilize existing innovation system structures that can be part of the regime.
Directionality	Encompasses the attention for the technology in focus and competition between underlying designs. Overlooks replacement effects.	Encompasses the attention for the mission formulation and underlying societal problem(s), as well as attention for the competing sets of innovative and 'phase-out' solutions.

The MIS builds on an adapted version of the structural-functional approach applied to the TIS (Hekkert et al., 2007). This adapted structural-functional approach consists of five analytical steps to identify barriers inhibiting the development and diffusion of innovative solutions and to provide recommendations for mission governance actions (Bergek et al., 2008; Hekkert et al., 2007; Wieczorek & Hekkert, 2015).

2.3.1. Step 1 – Problem-solutions diagnosis

The societal problems and solutions of the mission are inventoried to understand the full scope and complexity (Wesseling & Meijerhof, 2021). The way that different societal problems are included and prioritized within the mission formulation is known as *problem directionality*. The problem directionality determines what solutions are relevant for the mission. The *solution directionality* refers to how stakeholders determine what solutions look promising to fulfill the mission. It is important to see how other societal problems are involved in the problem framing that defines desirable solutions (Hekkert et al., 2020). Sandén and Hillman (2011) created a framework that can be used to study how the solutions interact in a positive, negative, neutral, unilateral or multilateral way. The phase-out or the *exnovation* of harmful practices and technologies such as fossil-fuel-based technologies also needs to be included (David, 2017; Kivimaa & Kern, 2016). Through destabilization or pressuring the regime the coordination of solutions and their phase-out becomes more important in the MIS (Wesseling & Meijerhof, 2021).

2.3.2. Step 2 – Structural systems analysis

The structural system analysis includes the actors, networks, institutions, and materiality (Bergek et al., 2015). Wesseling & Meijerhof (2021) distinguish between the *mission arena* and the *overall MIS* (Figure 2) and conceptualize the mission arena as *"those actors that are engaged in the highly political, and often heavily contested process of directing the MIS and building up its structural components"* (p. 6). The actors in the mission arena are involved in four tasks: setting up the mission arena, formulation of the mission, the mobilization of MIS components, and the continued mission governance via monitoring, coordination, evaluation, and reflexive redirection of the mission (Wesseling & Meijerhof, 2021; Janssen et al., 2020). The overall MIS is defined by a much larger group of for instance industrial actors and users that legitimize, develop, diffuse, and adopt the mission's solutions (Wesseling & Meijerhof, 2021). The mission area plays a central directing and system building role in the MIS, but the mission's success depends on mobilizing a larger group in the overall MIS. Therefore, the mission arena aims to mobilize the structural components of existing innovation systems. These MIS components are mobilized via mission governance actions which include MIP instruments implemented by governmental organizations, as well as measures to mobilize components undertaken by other stakeholders in the mission arena (Wesseling & Meijerhof, 2021).

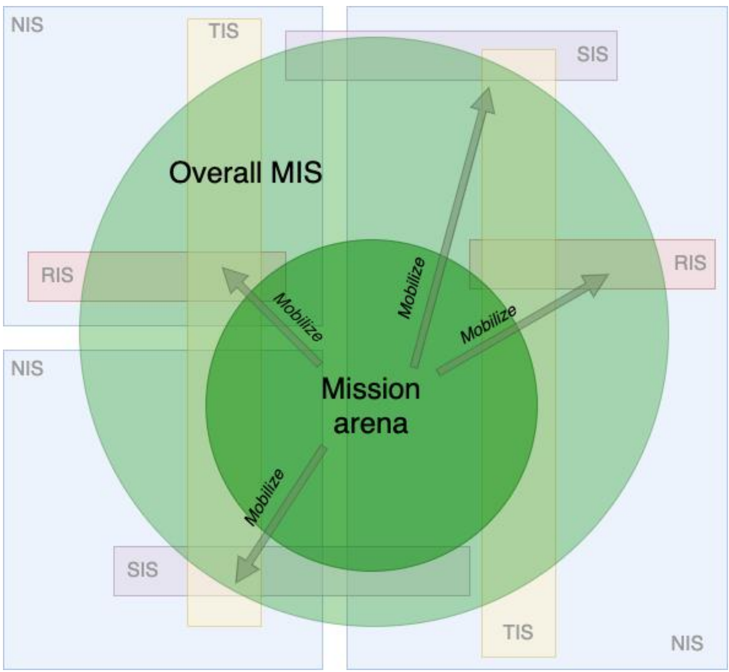

Figure 2, The mission arena aiming to mobilize other, existing innovation systems structured into an overall, well-performing MIS (Wesseling & Meijerhof, 2021, p. 9)

2.3.3. Step 3 – System functions analysis

The system functions developed to study TIS are adapted and reinterpreted to use them in the MIS (Table 3) (Bergek et al., 2008; Hekkert et al., 2007). Solution coordination is required since there is more interrelatedness of solutions than in a TIS (Bergek et al., 2015). Therefore, the TIS system function 'guidance of the search' is divided into problem directionality and solution directionality. The TIS does not include a function to monitor or evaluate the progress of the mission, therefore another dimension to directionality is added: *reflexivity* (Wesseling & Meijerhof, 2021). Reflexivity may result in readjustment of the problem and solution directionality. For each system function a set of diagnostic questions is composed to obtain data if current MIP adequately addresses the systemic barriers. The system function fulfilment can either be positive or negative. Positive fulfilment connotes activities that support the mission's goals, support solutions and the phase-out of harmful practices and technology. Conversely, negative fulfilment signifies a decrease in activities, reduced mission legitimacy and an increase in harmful practices (Suurs & Hekkert, 2009). To further distinguish the difference between innovation and the phase-out activities, functions SF2, SF5 and SF6 and SF7 are divided into separate functions to specifically analyze what the implications are for the mission's success (see *Table 2*).

Table 2, Description of system functions for MIS analysis building on TIS-related system functions from "Development and application of the Mission-oriented Innovation Systems (MIS) approach (working paper)" by J.H. Wesseling and N. Meijerhof, 2021, pp. 8-10, Copernicus Institute of Sustainable Development, Utrecht *University*

System function	**Interpretation**
SF1: *Entrepreneurial activities*	Experiments with (clusters of) solutions to enable learning; entering markets for new solutions; engaging in business model innovations to the diffusion of solutions.
SF2: *Knowledge development (contributing to the mission and phase-out of harmful activities)*	Learning by searching and 'doing' resulting in development and better understanding of new technical and social knowledge on problems and solutions, through R&D, social and behavioral science research. Also focus on knowledge development to *unlearn* practices harmful to the mission.
SF3: *Knowledge diffusion*	Stakeholder meetings, conferences, governance structures, public consultations, mission progress reports and other forms of disseminating technical and social knowledge for the mission's solutions and societal problems.
SF4: *Providing directionality*	Aside from pre-existing institutional structures in the context of the mission arena, the mission arena is central to providing direction and mobilizing support from the existing innovation system structures that comprise the overall MIS.
4A: *Problem directionality*	The direction provided to stakeholders' societal problem conceptions and the level of priority they give it.
4B: *Solution directionality*	The direction provided to the search for technological and social solutions, as well as the coordination efforts needed to identify, select and exploit synergetic sets of solutions

	to the mission.
4C: *Reflexivity*	Reflexive deliberation, monitoring, anticipation, evaluation and impact assessment procedures; these provide the analytical and forward-looking basis for redirecting the system's problem framing and search for solutions based on lessons learned and changing context. Reflexive governance can be seen as second-order directionality, and it can be initiated by the mission arena or by critical outsiders.
SF5: *Market formation and destabilization*	Creating niche market and upscaling support for technical and social solutions; phasing out or destabilizing markets for practices and technologies harmful to the mission.
SF6: *(De)mobilization of resources*	Mobilization of human, financial and material resources to enable all other system functions.
SF7: *Creation of legitimacy and counteracting resistance to change*	Creating legitimacy for prioritizing the problem and the development and diffusion of its solutions, at the cost of harmful practices and technologies.

2.3.4. Step 4 – Systemic barriers analysis

The systemic barriers of an MIS are analyzed to discover the underlying root causes for weak fulfilled system functions. These barriers are identified via document analysis and follow-up questions in semi-structured interviews. During this step, the interrelatedness between different barriers is identified which may cause systemic lock-in (Kieft et al., 2016; Wesseling & Van der Vooren, 2017).

2.3.5. Step 5 – Evaluation of governance actions

Systemic instruments are policy or governance actions that aim to address the root cause of the identified barriers preventing mission success (Smits and Kuhlmann, 2004; Wesseling & Van der Vooren, 2017). The recommendations for these instruments can be defined as formative recommendations to address the MIS barriers that are currently not addressed by MGAs, or that are reinforced unintentionally by ongoing or planned MGAs (Wesseling & Meijerhof, 2021). If the MGAs do not adequately support the mission's goals the effectiveness is low as some barriers might not be addressed by these actions. Recommendations could include to adjust MGAs to make them able to address the systemic barriers. More generic mission governance recommendations can be added to the policy mix if no MGAs have been formulated yet. An ex-post, summative evaluation of a mission can also be conducted to see why a mission has or has not been successful (Wesseling & Meijerhof, 2021).

2.4. International context

Literature on how MIP relates to its geographical scope and ensuing coordination problems is currently underdeveloped (Wanzenböck & Frenken, 2020). This thesis aims to further substantiate MIS components in an international context. This context is strongly determined by large actors, strong networks and dominant institutions, such as large supranational entities mobilizing existing structures to develop and diffuse solutions. It is important to align the underlying institutional structures of the mission with the existing structural components (Wesseling & Meijerhof, 2021). In the international context, tackling a societal challenge such as climate change is often linked to the creation of a (global) public good that will provide a large-scale solution for reducing emissions. It is expected that the benefits will spread across the world, which might be tempting for policymakers at the (sub)national level to invest too little and free ride on the efforts of others (Wanzenböck & Frenken, 2020).

Fuenfschilling & Binz (2018) introduce the global socio-technical regime and define this as "*the dominant institutional rationality in a socio-technical system, which depicts a structural pattern between actors, institutions and technologies that has reached validity beyond specific territorial contexts, and which is diffused through internationalized networks*" (p. 739). Fuenfschilling and Binz (2018) argue that despite the spatially open definition of the regime concept, empirical studies have tended to analyze socio-technical regimes at a national level. Therefore, there is little known about how, where, and by whom dominant regime rationalities have developed and where they exert influence. Global regimes are conceptualized as a semi-coherent and multi-scalar institutional rationality where different types of actors will have varying influences on the dominant institutional rationality to change the trajectory of the regime (Fuenfschilling & Binz, 2018).

A study by Kieft et al. (2018) showed that in international sectors characterized with a lot of competition to make short term profits, there are low profit margins. These low profit margins make it difficult for actors in the sector to allocate resources to develop and diffuse sustainable innovations. The pressures stemming from this competition make it difficult for governments to issue a supportive policy framework in a sector that is highly international. Institutional factors can therefore have a strong influence and this thesis aims to understand how large actors and strong networks with an institutionalized international context exert influence on the structural components in the mission arena and overall MIS (Figure 3). An improved understanding of how these dominant actors act and how the institutions affect the mission, guides analysts in their search for interactions. Likewise, it would also increase context-awareness amongst policymakers in which direction a mission strongly influenced by dominant institutions in an international context is developing.

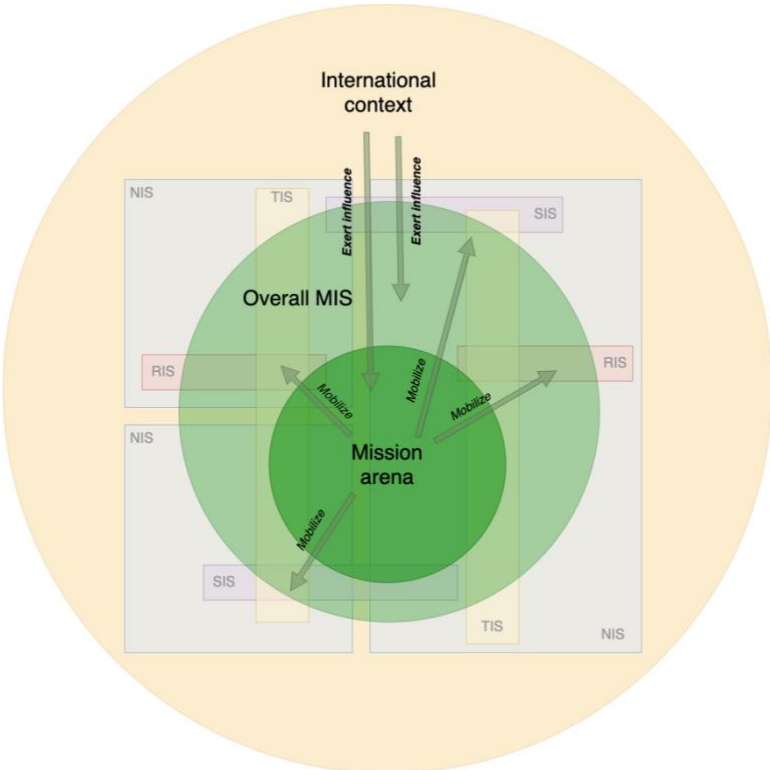

Figure 3, International context in relation to the mission arena and overall MIS

3. Methodology

3.1. Research design and analytical approach

This research is qualitative research using a case study design (Bryman, 2016). The five analytical steps of the adjusted structural-functional approach for the MIS framework were followed to answer the research questions. In this section, an outline is provided on how these steps were operationalized. An operationalization table can be found in Appendix IV. Furthermore, this section explains the data collection methodology and the applied sampling strategy.

3.1.1. Structural functional approach

Step 1 – Problem-solutions diagnosis

First, the societal problems, and technological and social solutions relevant to the mission were identified. Desk research provided literature and reports, and information was analyzed to identify about how these problems and solutions are related to the mission. Many policy documents were readily available to identify which problems relate to sustainability and how the mission was formulated. For the different solutions, policy documents, academic papers, and industry reports were used to identify the different technological and social solutions. The solutions were further elaborated by describing them in terms of radical versus incremental and in Technology Readiness Level (TRL) and Social Readiness Level (SRL) (see Appendix II). To further substantiate and confirm the findings, experts were consulted, and interview data was used. To reduce complexity, the technological and social solutions in this thesis will be assessed collectively in clusters and not individually.

Step 2 – Structural systems analysis

The actors, networks and institutions in the mission arena, overall MIS, and international context were determined through the use of literature, interview data, and expert consultations. In the mission arena, the actors involved in the set-up of the arena, the mission formulation, the mobilization of MIS components via MGAs, and its continued, reflexive mission governance were identified (Wesseling & Meijerhof, 2021). For the overall MIS, a larger group of industrial actors and users that legitimize, develop, diffuse and adopt the mission's solutions were identified (Wesseling & Meijerhof, 2021). Lastly, for the international context, the large entities active on the European and global levels were identified. The institutional alignment of the mission in an international context was assessed because this is relevant for solution development and diffusion. Lastly, the MGAs were identified and how they relate to the international context.

Step 3 – System functions analysis

From the structural analysis, a sample of actors in the mission arena, overall MIS, and international context is selected (see Section 3.1.3). A semi-structured interview guide is composed of a set of diagnostic questions based on the system functions (Appendix V & VI). The interview guide consists of open questions to find possible barriers inhibiting a system function and closed questions to see whether system functions are strong or weak fulfilled. These questions served as indicators to obtain data (see Appendix IV). The closed questions are made quantifiable using a Likert scale on a scale from 1 to 5 (Bryman, 2016). This scale was used to indicate the strong and weak fulfilled system functions. The aim is not to serve as a performance indicator of the system but to identify systemic problems and their root cause. Between 1 and 1,5 means very bad and thus a weak fulfilled system function, below 1,5 is very bad, 1,5-2,5 is bad, 2,5-3,5 is neutral, 3,5-4,5 is good and above 4,5 is excellent and therefore a strong fulfillment.

In addition, to measure the phase-out of harmful activities a distinction in system functions was made. The system functions 2, 5, and 6 were split into: 2a (knowledge development), 2b (knowledge development focused on the out phasing of harmful activities), 5a (market formation), 5b (market destabilization), 6a (resource allocation), and 6b (resource reallocation). This allowed the researcher to separately assess the innovation and *exnovation* activities in the system (Wesseling & Meijerhof, 2021). Consequently, the interviews were transcribed and analyzed. For each system functions the strengths, weaknesses, and barriers resulting from the weak fulfilled system functions were identified.

Step 4 – Systemic barriers analysis

From the weak fulfilled system functions the barriers were identified. A weak fulfilled system function did not mean that the root cause is stemming from this specific function. Other system functions could also be interrelated to the identified barriers. To find the underlying root cause and possible interrelatedness with a systemic lock-in of the weak fulfilled system functions each barrier is analyzed. The most pressing systemic problems are clustered and shown in flowcharts. To further substantiate, confirm and validate the findings, experts were consulted, and additional literature was used.

Step 5 – Evaluation of governance actions

Lastly, it was evaluated whether the identified MGAs from the structural analysis adequately addressed the identified barriers. If the MGAs adequately address them, the mission is likely to be successful. If the MGAs do not address the barriers adequately, recommendations and/or policy interventions were provided which aim to improve mission policy to eliminate or reduce the adverse effects of barriers that inhibit the diffusion and development of the mission (Janssen et al., 2020). Again, experts were consulted, and literature was used to cross-check the findings. The conclusion and discussion section in this thesis explains in detail the implications of the findings.

3.1.2. Data collection

Data was collected via desk research, expert consultations, and interviews. First, for desk research academic literature, documents and reports were the main sources of data. Online publications from sources such as LexusNexus, Web of Science (Wos), Google Scholar, government databases containing policy documents, and the Dutch Mobility Innovations (DMI) platform were used. Table 3 shows an overview with used keywords. Secondly, expert opinions were consulted via colleagues within the Ministry, research institutes, universities, online conferences with stakeholders, Sustainable Aviation Roundtable working group participation, other stakeholder meetings, and via contacts using the researcher's network on LinkedIn. Lastly, interview data were obtained via a semi-structured interview guide with open and closed questions as described in Section 3.1.1. The interviews were recorded using Microsoft Teams. The transcripts were processed using the online (paid) application *Trint*. The application *Nvivo* was used to process all codes (Bryman, 2016).

Table 3, Keywords desk research literature

Language	Keywords
English	Sustainable aviation, innovation aviation, carbon reduction aviation, international aviation, regulations, international agreements, *names of companies*, *names of NGOs*, *names of industry associations*, *names of governmental organizations*, *names of research institutes*, *names of technological solutions*, *names of social solutions*
Dutch	Duurzame luchtvaart, innovatie luchtvaart, koolstofdioxide reductie luchtvaart, internationale luchtvaart, regelgeving, internationale afspraken, *namen van bedrijven*, *namen van NGO's*, *namen van brancheorganisaties*, *namen van overheidsinstanties*, *namen van onderzoeksinstellingen*, *namen van technologische oplossingen*, *namen van sociale oplossingen*

3.1.3. Sampling strategy

The initial approach was to interview a representative sample of about 20-25 interviewees. The selection of interviewees was based on a representative number of identified actors from the structural analysis active in the mission arena, overall MIS, and international context. A total of 46 invitations were sent and eventually 29 of these interviewees participated. Through snowball sampling, three additional interviewees were recommended for an interview. Due to a higher-than-expected positive response rate, finally a total amount of 32 interviews were conducted for this thesis.

Clusters of interviewees were categorized as shown in Table 4. A total of 28 interviewees were held in Dutch and four interviews were conducted in English. The Dutch interviews were held in Dutch because the interviewees felt more comfortable speaking their mother tongue. This would also reduce possible misinterpretation of wording (Bryman, 2016). The English-speaking interviewees were all non-Dutch speakers and active in an organization in the international context. Both interview guides are to be found in Appendix V and VI.

Table 4, Dataset interviewees per category

Actor category	Abbreviation (amount)
Aircraft OEM	OM (4)
Airline	AL (2)
Airport	AP (1)
Entrepreneur	EN (1)
Fuel company	FC (2)
Ground handler	GE (1)
Industry association	IA (5)
Knowledge institute	KI (4)
Non-governmental Organization (NGO)/Civil society	NG (3)
Policymaker	PM (4)
Railway company	RW (1)
Regional development agencies	RD (2)
University	UV (2)
Total:	32 interviewees

3.2. Data analysis

A thematic analysis was conducted to identify concepts in the interview transcripts (Bryman, 2016; Verhoeven, 2020). This practical instrument was used because it allows identifying patterns in a less complex and more time-efficient manner in qualitative data. For this thesis, a thematic analysis approach was chosen because the grounded theory approach is deemed too 'heavy' (Verhoeven, 2020). The result is an extensive overview with a contextual interpretation of the data to answer the research questions (Braun & Clarke, 2006). The thematic analysis consists of three phases and six steps (Braun & Clarke, 2006; Verhoeven, 2020). These steps are explained below and shown in Table 6.

The interview data was processed into transcripts. This resulted in a total of 442 pages of transcripts with over 280.000 words. These transcripts were multiple times read and text fragments were created of relevant passages and topics. Initial nodes and codes were created from these fragments, resulting in a total of 782 nodes. Next, the codes are further categorized and divided across themes. These themes were based on the system functions from the MIS framework. Fragments that did not belong across any of the system functions were categorized as 'other'. Codes and categories were checked and rearranged if necessary and applicable. This resulted in a reduction of codes. Eventually, a total amount of 524 codes remained. For each system function, this resulted in the number of codes as shown in Table 5.

Table 5, Codes per system function

System function		Codes
SF1	Entrepreneurial activities	55
SF2a/b	Knowledge development (including phase out of harmful practices)	49
SF3	Knowledge diffusion	51
SF4a	Problem directionality	55
SF4b	Solution directionality	54
SF4c	Reflexivity	16
SF5a/b	Market formation and destabilization	111
SF6a/b	Resource (re)allocation	50
SF7	Creation of legitimacy and counteracting resistance to change	35
	Other	48
	Total:	524

The system function scores were processed into a spider diagram using the average scores by each actor category and the total average. The standard deviation was calculated to explain possible variance in the data. The next step was to specify the relations between the system functions. The identification of systemic problems and their root causes was part of this process. Finally, for the reporting step the most pressing systemic problems were selected based on the interview data. These findings were further analyzed through triangulation. Numerous expert consultations were conducted and numerous articles from online literature databases were used for substantiation. By comparing interview results with literature, the consistency of the findings was thoroughly checked. This process was iterated until no new findings were found (Bryman, 2016).

Table 6, Thematic analysis phases and steps

Phase and step	Description
Phase 1 – Exploration	
1) Familiarization 2) Initial coding and creation of categories	Orientation of interview data. Reading and re-reading, making fragments of text from each transcript. From these fragments, initial codes are created. Recurring topics in the data are coded and clustered into categories (nodes).
Phase 2 – Reduction	
3) Search for themes 4) Review and refinement of themes	Codes are grouped and further categorized. The seven system functions served as themes for each category. Those codes not matching with one of the system functions were coded as 'other'. Codes were checked and regrouped if necessary.
Phase 3 – Reflection	
5) Definition and naming of themes 6) Reporting	Relations between the themes (*system functions*) were specified. This step is step 4 of the structural-functional approach in the MIS analysis to identify root causes and interrelatedness. The reporting step is the systemic barrier analysis and systemic instrument analysis.

3.2.1. Reliability and validity

This section explains how reliability and validity were ensured. To ensure internal reliability and prevent personal bias, an intercoder reliability check was conducted by four peer researchers experienced with performing an MIS analysis. Krippendorff's Alpha was used to measure the internal reliability (Krippendorff, 2004). Each observer studied 25 statements (N=125) from the interview transcripts and assigned them to the corresponding system function. The result is a Kalpha of 0,8376 which is considered reliable, because it is above 0,8 (see Appendix VII) (De Swert, 2012). External reliability was difficult to achieve since it is impossible to freeze social conditions (LeCompte & Goetz, 1982). Due to the temporality of missions changing conditions occur over time (Hekkert et al., 2020). To ensure external reliability, each step of the analytical framework is described in as much detail as possible for other researchers to increase the replicability of this research. To ensure internal reliability, a match between theory and observations is preferred (Bryman, 2016). By making an evaluation of planned and recently implemented MGAs using the MIS framework, a systemic approach is ensured. Achieving external validity is harder for qualitative research in general, because the findings need to be generalizable (Bryman, 2016). For this research, it was important to focus on the characteristics of the MIS dynamics. By closely focusing on how case-specific findings can be coded into the system functions a more generalizable outcome for missions could be obtained.

3.3. Ethical issues

In this section, ethical issues concerning interview data are addressed. Before conducting each interview, the interviewee was explicitly asked to give his or her consent to start an audio recording. Each interviewee was informed that data will be processed confidentially and reported and/or published anonymously. It was emphasized that each interviewee could speak out freely. All names, companies, ways of quoting, and other recognizable characteristics of the interview were processed in such a way that anonymity is guaranteed as much as possible. Unpublished and confidential documentation, media, and other data would be handled with the utmost care and restraint. Data used during the research were processed in agreement with the supervisor(s) before it was shared or made public to avoid disputes about confidentially or intellectual property rights.

4. Results

This section shows the results from the adjusted structural-functional analysis for the MIS (Wesseling & Meijerhof, 2020). First, the problem-solution diagnosis explains which problems are included and prioritized in the mission formulation and what solutions are involved in the reduction of CO_2. Secondly, the structural analysis shows the structure of the innovation system and the governance structure including Mission Governance Actions (MGAs) and their interaction with the international context. Thirdly, the system function analysis elaborates how strong each system function is fulfilled including strengths, weaknesses, what the systemic barriers are and what their possible root cause is. Fourth, the systemic barriers are further analyzed to see how they interrelate with other system functions and the international context, and where the root cause is stemming from. Lastly, the proposed policy interventions are outlined for the barriers that are not targeted by MGAs.

4.1. Problem-solutions diagnosis

4.1.1. Societal problems related to the mission

In this section, the interrelated societal problems and how they are prioritized in the mission formulation are discussed. This is also one of the four tasks to mission governance as distinguished by Wesseling & Meijerhof (2021). The aviation sector has to reduce its carbon emissions like any other sector to comply with the goals agreed upon in the Paris Agreement (Rijksoverheid, 2020a; Transport and Environment, 2016). For each country, emissions of domestic aviation and ground operations are included in the Nationally Determined Contributions (NDCs). For international aviation, the emissions are excluded from the NDCs due to the difficulties in accountability between countries (ATAG, 2019). The complex international processes concerning these difficulties are covered by the International Civil Aviation Organization (ICAO). This United Nations (UN) organization makes agreements for carbon reduction in international aviation with each member state. Two global aspirational goals to promote sustainable growth have been defined. These goals include an annual 2% fuel efficiency improvement through 2050 and a carbon-neutral growth from 2020 onwards (ICAO, 2019). ICAO (2019) recognizes that efficiency improvements and market-based measures alone are unlikely to achieve the reduction goals. Therefore, ICAO is also working on a long-term aspirational goal (LTAG) with more far-reaching measures for international aviation to reduce its emissions. The LTAG is expected to be presented in 2022 (ICAO, 2019). In addition, the global aviation industry has committed itself to cut net carbon emissions to half of what they were in 2005 by 2050 (ATAG, 2020). Moreover, the European Commission has set out transport emission reductions via the European Green deal. The aviation sector has to contribute to a net reduction of 90% by 2050 (compared to 1990-levels) for transport emissions (EEA et al., 2019).

Complementary to these international goals, the Dutch government has formulated its own ambitious national climate approach for its aviation sector (Rijksoverheid, 2020a). The Dutch government anticipates the LTAG and European Green Deal reductions. If more far-reaching agreements are made on an international level, the Netherlands pledges to align its national aviation goals accordingly (Rijksoverheid, 2021). This is shown by the fact that the NDCs and the international air traffic emission reduction targets for the Netherlands are outlined in the Sustainable Aviation Agreement (SAA) (see Section 4.2). The SAA is incorporated in the *Luchtvaartnota* (Dutch Civil Aviation Policy Memorandum). The most recent policy memorandum was released in November 2020. The policy memorandum outlines policy and solutions on how to reach a sustainable aviation sector towards 2050. International reduction targets for flights departing from the Netherlands are based on how much fuel is uplifted at Dutch airports (Rijksoverheid, 2020a). The reduction targets for international CO_2 emissions, which is the mission discussed within the scope of this thesis, are: in 2030 minimally down to 2005 levels, in 2050 a 50% gross reduction compared to 2005 levels, and for 2070 zero emissions in the sector (Rijksoverheid, 2020a). The 2030 goal is adapted from the industry action plan *slim en duurzaam* (smart and sustainable, see Section 4.2). The main difference between the ICAO, industry, and EU goals for 2050 and the Netherlands is a net versus gross reduction. The Netherlands aims to achieve a gross carbon reduction, meaning within the sector. This makes the memorandum unique because no other country or international organization has pledged to realize reductions without the use of market-based measures to compensate in other sectors at this moment (Rijksoverheid, 2020a). The 2070 goal is indicated as a 'point on the horizon' to achieve zero emissions (Rijksoverheid, 2020a). When looking at the Dutch reduction targets for other industry sectors, aviation seems to have less stringent reduction targets at this moment. Other sectors have to realize net carbon reductions of 90% compared to 1990 levels in 2050 as stated in the European Green Deal (European Commission [EC], 2017). Consequently, other sectors might have to put extra effort to compensate for aviation until 2070.

Next, carbon reduction has gained a lot of priority on the sustainability agenda of the government and industry actors over the last couple of years. Within the industry, there has always been an intrinsic motivation to reduce costs by making airplanes more fuel-efficient and thereby also avoiding emissions (see Section 4.1.2). In the policy memorandum, a framework with public interests (Figure 4) depicts the societal 'wants' and 'needs' and their interrelatedness using the three elements of People Planet Profit. Sustainability (*climate*) is one of the pillars alongside safety, economy/connections, and quality of life (*liveability*) of which the latter mostly concerns externalities from noise and local air pollution and their effects on health and biodiversity (Rijksoverheid, 2020a). The COVID-19 pandemic has an immense impact on the aviation sector with global air-passenger volume shrinking by 64% in August 2020 compared to August 2019 (Bouwer et al., 2021). Yet, 15 interviewees agreed that the path with a focus on sustainability will be followed during recovery. According to Bouwer et al. (2021) aviation will be back at 2019 air-passenger volume levels in 2024. This shows that there is an enormous demand for air travel around the world after COVID-19. Therefore, without more sustainable alternatives for aviation emissions are likely to rise.

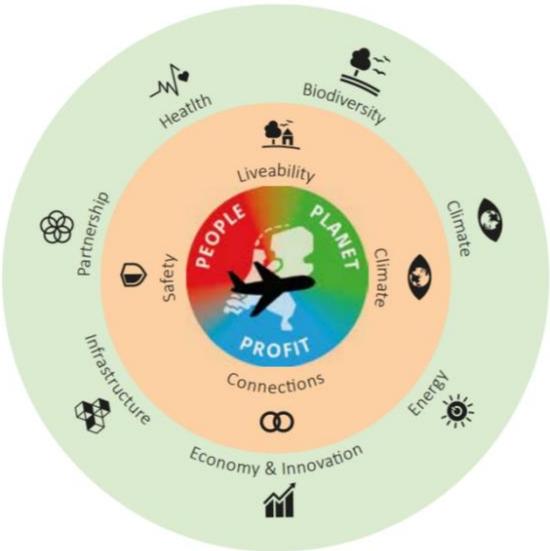

Figure 4, Relationships between aviation and quality of the environment (Rijksoverheid, 2020a)

4.1.2. Technological and social solutions relevant to the mission

Many different technological (12) and social (7) solutions to abate carbon emissions in the aviation sector have been identified. Before elaborating the different clusters of solutions (Figure 5), the dominant aircraft design is described to understand how technological trajectories have evolved in this specific mission. The dominant design for aircraft is the 'tube and wings' configuration (Peeters & Melkert, 2021). In this configuration, the fuselage provides room for passengers and/or freight while wings on each side of the fuselage provide lift. There are two or more engines connected to the wing (and sometimes to the fuselage itself) to propel the aircraft (Peeters & Melkert, 2021). Fuel is stored in the wings and the horizontal and vertical stabilizers provide stability to control the aircraft. This design has been greatly optimized since the 1960s. Many incremental innovations have delivered over 80% improved efficiency over the years (ATAG, 2020). These efficiency improvements still take place today to improve aerodynamics and fuel consumption. However, according to 8 interviewees and multiple sources of literature, these improvements alone are not sufficient to achieve the emission reduction targets (ATAG, 2019; Van der Sman et al., 2021). The absolute growth of aviation is faster than the relative carbon reduction achieved by efficiency improvements (Peeters & Melkert, 2021). Therefore, other technological- and social solutions are needed which are discussed below. Figure 5 shows a simplified overview with all possible solutions

(Peeters & Melkert, 2021). Appendix II shows a more extensive tabulated overview of the technological and social solutions, their TRL/SRL, and the (dis)advantages.

Technological solutions

For aviation, the technological solutions can be divided into renewable fuels and alternative aircraft designs and propulsions. The renewable fuels are further divided into Sustainable Aviation Fuels (SAFs) that can be used in current aircraft (biofuels, waste fuels, and synthetic fuels) and hydrogen which is considered an alternative fuel used for alternative propulsions (Van der Sman et al., 2021). Alternative aircraft designs include the beforementioned incremental efficiency improvements and more radical improvements such as new types of wings and aircraft bodies (Peeters & Melkert, 2021). The alternative propulsions are electric, fuel-cell, and hybrid propulsion systems that aim to avoid the usage of conventional kerosine turbine engines (Peeters & Melkert, 2021).

a. Renewable fuels

The most potential impact on the short to medium-term according to 11 interviewees is expected from Sustainable Aviation Fuels (SAFs). These so-called 'drop-in' fuels can be used in (slightly adjusted) aircraft engines and are compatible with existing infrastructure (Peeters & Melkert, 2021; Van der Sman et al., 2021). The identified SAFs are biofuels, waste fuels, and synthetic fuels. The current production is according to 6 interviewees negligible, and they require a large amount of energy to be produced. Synthetic fuels are the most sustainable one as these are e-fuels and do only require electricity for its production (Peeters & Melkert, 2021). However, the required energy for production is significant due to chemical processes (Van der Sman et al., 2021). Biofuels require feedstock from croplands, taking a lot of space in potentially sensitive areas. Waste fuels use waste as a resource, which is not available in sufficient quantities for upscaling, while it could possibly also be contradicting with waste reduction goals for circularity if it gets financially more attractive to produce more waste (Peeters & Melkert, 2021). Prices are also higher compared to conventional Jet A1 kerosene fossil fuel, especially for synthetic kerosene which are around six times higher (Van der Sman et al., 2021). Lastly, hydrogen is considered a renewable fuel as well when green energy is used for its production. Hydrogen can be used both as an energy source for the production of SAFs and directly in liquid or gaseous state as fuel for alternative propulsions (Peeters & Melkert, 2021).

b. Alternative aircraft designs and propulsions

First, in short term there are incremental innovations to improve aerodynamics (such as winglets) and fuel efficiency (improved engines) (Van der Sman et al., 2021). In the longer term, more radical innovations such as new aircraft designs and different ways of powering the aircraft are indicated as potential technological solutions to lower carbon emissions in aviation (Peeters & Melkert, 2021). A lot of research has been conducted on alternative aircraft designs such as the 'blended wing body'. In this design, the fuselage and wings are integrated making it more aerodynamic and more fuel-efficient. Still, many technological challenges are encountered for alternative aircraft designs before a commercial application is possible (Peeters & Melkert, 2021).

In addition, alternative propulsions are researched to replace the current type of turbine engines. Possible solutions are electrical flying with engines using batteries or hydrogen (fuel cell). Another option is by using hydrogen directly as a fuel source in current turbine engines. A combination of both or either one combined with conventional fuel (hybrid) might also be a possible solution. The downside is that these new propulsion technologies take a long time to be developed before becoming available for commercial use. There are also many challenges such as weight and technology-related issues that need to be overcome (Peeters & Melkert, 2021). These technologies are therefore still in a low TRL facing many challenges and will, according to 5 interviewees, not be available soon for commercial application.

Social solutions

For social solutions, the '*Kennisinstituut voor Mobiliteitsbeleid'* (Netherlands Institute for Transport Policy Analysis) (KiM, 2020) has researched the impact of behavioral interventions for sustainable aviation. The researchers have identified ten possible solutions (KiM, 2020). In Figure 5, the most promising solutions are arranged in terms of alternative transportation modes, consumer awareness and behavior, and as a third category of social solutions, optimization of Air Traffic Management (ATM) and aircraft operations are identified. This category has a technological component which is explained below.

a) Optimization of Air Traffic Management (ATM) and aircraft operations

First, 7 interviewees state that incremental innovations during flight operations such as the optimization of ATM and optimizing aircraft operations are “the low-hanging fruits to achieve some of the necessary reduction, but more is needed” (UV1). Examples are a more unified network structure for European airspace and avoid the influence on flight routes, resulting from military matters, national borders, and predetermined air corridors (Heinrich Böll Foundation, 2016). By shortening, flight routes and more precise navigation methods such as Air Traffic Controller (ATC) continuous descent procedures and traffic flow management, fuel and therefore CO_2 can be reduced. More efficient procedures also include for instance weight savings, single-engine taxiing, and idle reverse thrust (IATA, 2021). These solutions have also a technological component since there is a lot of technical knowledge and management of data required to understand how to improve the operations (Van der Sman et al., 2021).

b) Alternative transportation modes

Alternative transportation modes with a lower carbon footprint could be used to substitute flights. These alternative modes include for example electric rail and bus (KiM, 2020; CE Delft, 2019). The target audience is relatively small at the moment and therefore the benefits are hard to determine (KiM, 2020). This is caused by the fact that there need to be more short distance destinations available by train that are competitive compared to flying in price, comfort, and travel time (Rijksoverheid, 2020b). It is also unclear whether new passengers would be attracted to take place on the available seats. This increased demand would mean that there is no reduction of carbon emissions in aviation, as flights are not reduced. While there is a high willingness by consumers to replace their flights with other ways of transport, the management of unintended consequences is necessary and therefore deserves consideration (KiM, 2020)

c) Awareness and consumer behavior

This category consists of three parts. The first part is about the communication of the impact of flying. Carbon labeling of transport aims to promote the understanding of travelers their impact of flying. If passengers would decide to select a ‘clean’ airline that uses a newer fleet of more fuel-efficient aircraft this could mean the passenger reduces his or her footprint (KiM, 2020). These eco-labels aim at a large target audience, but their overall effect could be limited as it concerns an individual choice (KiM, 2020).

The second category is about reduce or refuse the amount of flying. If passengers decide to fly less often or less far this results in lower carbon emissions unless another passenger takes place on the seat (KiM, 2020). A new social norm could be established in which flying multiple times and/or to a faraway destination is deemed unacceptable by society (KiM, 2020). Passengers can for instance adapt to achieve their purpose of travel goals at shorter distances (Peeters et al., 2021). According to 9 interviewees, it would take a long time for this to become the new standard. Refusing to fly is the most extreme solution, as passengers would completely abandon flying. It would require great efforts to establish a cultural change that could restrict the movement of people and their feeling of freedom (KiM, 2020).

The third category is CO_2 compensation. Passengers could decide to compensate the emissions of their flight by for instance investing financial resources in trees or sustainable projects in other sectors. The effects are hard to manage and are relatively small, but it does deserve consideration.

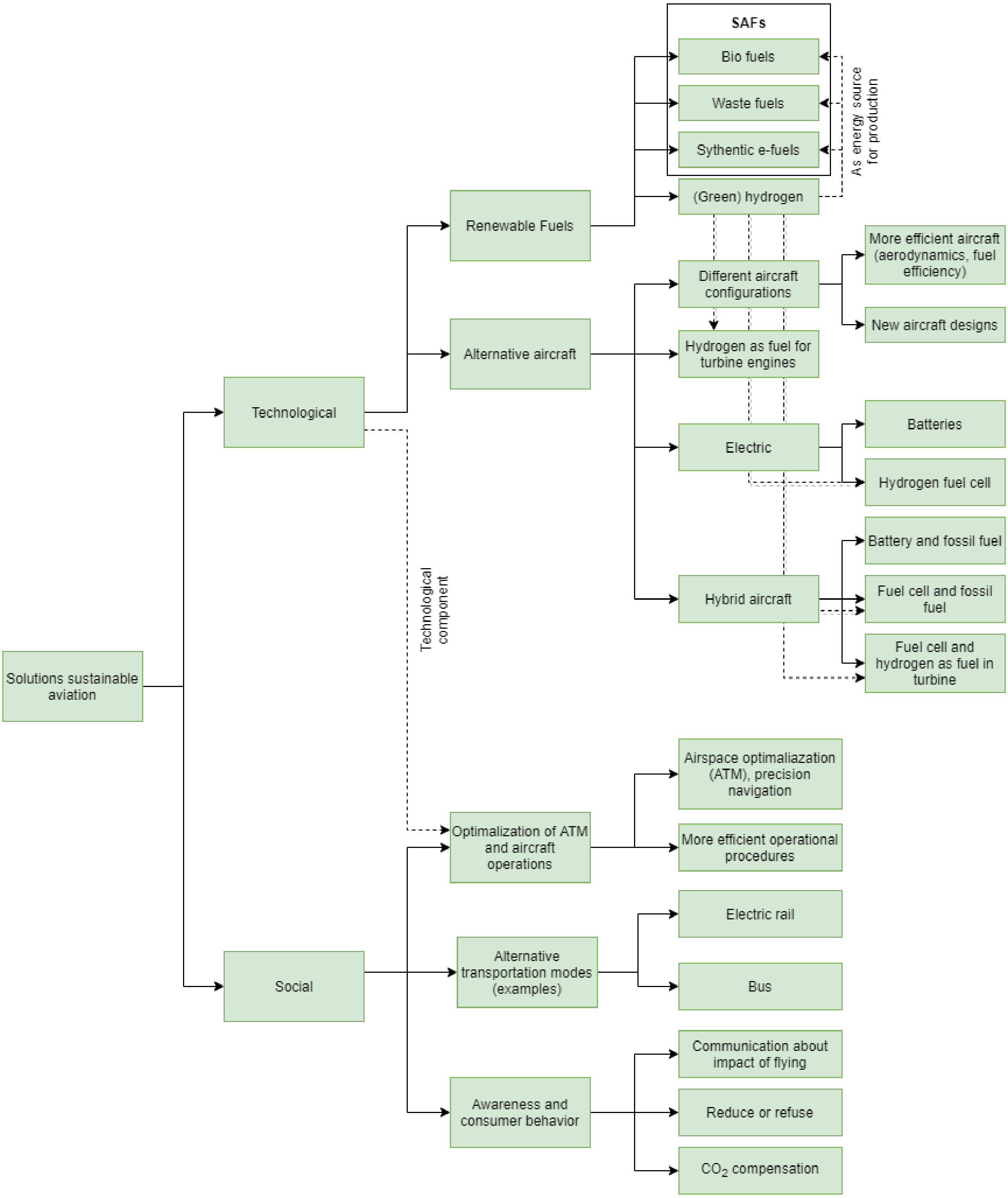

Figure 5, Possible developments for sustainable aviation using technological or social solutions. Adapted from (Peeters & Melkert, 2021)

4.2. Structural systems analysis

This section shows the structural components of the MIS. These are the actors, networks, and institutions of the MIS (Bergek et al., 2015). The four tasks of mission governance as distinguished by Wesseling & Meijerhof (2021) are explained in this section. In the first section, the way the mission area is set up is explained, the way structural components in the mission arena and overall MIS are identified, and the continued reflexive governance of the mission is elaborated. The mission formulation has already been explained in Section 4.1. In the second part of this section, the structural components in the international context and their interactions with the focal mission are explained. The third section explains the different MGAs on national and international levels relevant to the mission and how MIS components are mobilized via these MGAs.

4.2.1. Structure and governance of the mission

Setting up the mission arena

In 2018, twenty actors[1] from the aviation industry in the Netherlands presented the industry-initiated action plan *Slim en Duurzaam* (Smart and Sustainable) which describes goals to reduce CO_2 and corresponding MGAs to achieve these goals (Schiphol, 2020). In February 2019, this action plan and the draft *Luchtvaartnota* (Dutch civil aviation policy memorandum) formed the base for the more important *Akkoord Duurzame Luchtvaart* (Sustainable Aviation Agreement, or SAA) (Duurzame Luchtvaarttafel, 2019). The SAA is broadly supported by many stakeholders and institutions. The signatory parties[2] are amongst those who signed the Smart and Sustainable action plan. The SAA served as a base for the final policy memorandum which was released in November 2020. The majority of signatory parties of the SAA are participating at the *duurzame luchtvaarttafel* (Sustainable Aviation Table, or SAT). Together with the Ministry of Infrastructure and Water Management (I&WM) and Ministry of Economic Affairs and Climate Policy (EZK), these parties are involved in the negotiation and decision-making in the mission arena.

The SAT is the body that directs the mission and mobilizes the innovation system structure. According to 7 interviewees, such a roundtable is unique compared to other countries where many parties are talking and coordinating with each other directing and mobilizing the mission of sustainable aviation. The SAT is a platform where actors are meeting each other and agree on what actions to take. The SAT as a platform in its current form has no mandate. The government ultimately decides what policy instruments are implemented and the companies and organizations decide what actions to take within their businesses. In total 34 actors are participating in the roundtable (see Appendix I). These are airlines operating in the Netherlands (5), airports (3), consultancy (2), employees associations (3), the energy sector (fuels) (4), ground handlers (1), manufacturing industry (4), travel agencies (1), industry associations (5), infrastructure (1), knowledge institutions (2), and the government (3). During the negotiations, one NGO was involved in drafting the SAA, but according to this organization, the reduction targets were not ambitious while also the MGAs were according to this stakeholder insufficient to achieve the agreed reduction targets (NG1). While this NGO left the negotiations and is not participating at the SAT as an active member, it is still influencing the mission arena through participating in the working groups and action programs. Furthermore, in the overall MIS, there are many component manufacturers, small and medium enterprises (SMEs), entrepreneurs, regional development companies, NGOs, and civil society organizations active that mobilize or are mobilized by the structural components within the mission arena. SMEs are small aviation companies which are mainly active in general aviation. The scope of this mission is not focused on general aviation, and therfore not on domestic emissions. However, SMEs can contribute a great deal as a platform or testing ground for experimentation of potential disruptive technologies according to 6 interviewees (see Section 4.3.1). Therefore, the general aviation actors such as SMEs are also included in the scope. While the aim of this thesis is the achieve the targets for international aviation, these pilot projects and tests on domestic level

[1] ACN, BARIN, Corendon, Dutch Aviation Group, Easyjet, Eindhoven Airport, Evofenedex, KLM, Lelystad Airport, LRN, LVNL, NLR, NS, Rotterdam The Hague Airport, Royal Schiphol Group, SkyNRG, Transavia, TU Delft, TUI, VNO-NCW

[2] ACN, AOPA, BARIN, Corendon, DNATA, Easyjet, Eindhoven Airport, Evofenedex, Fokker GKN, KLM, KNVvL, LRN, LVNL, NACA, NLR, NVL, Ministry I&WM, PwC, Royal Schiphol Group, SkyNRG, Transavia, TU Delft, TUI, VNO-NCW

could contribute substantially to experiments and potentially the possibility to upscale it to larger aircraft.

Continued reflexive governance

Figure 6 shows the structure of the SAT. The table is comprised of one central table and three working groups: information, sustainable aviation fuels, and innovations. These working groups are working on six different action programs each contributing to achieving the mission's goals through mobilizing the other structural components in the mission arena and overall MIS. There are program managers commissioned by the government taking the lead to make sure that each action program will be active while also ensuring that no overlap between the programs takes place. The SAT aims to mobilize networks of knowledge institutes, the government, the Dutch (and international) aviation sector, industry, and other companies in the overall MIS to combine their strengths to foster innovation, for instance via living labs and experience centers (Duurzame Luchtvaarttafel, 2019). At this moment there is no mission progress monitored or evaluated yet, as many of the MGAs are still work in progress as will be explained in Section 4.3.

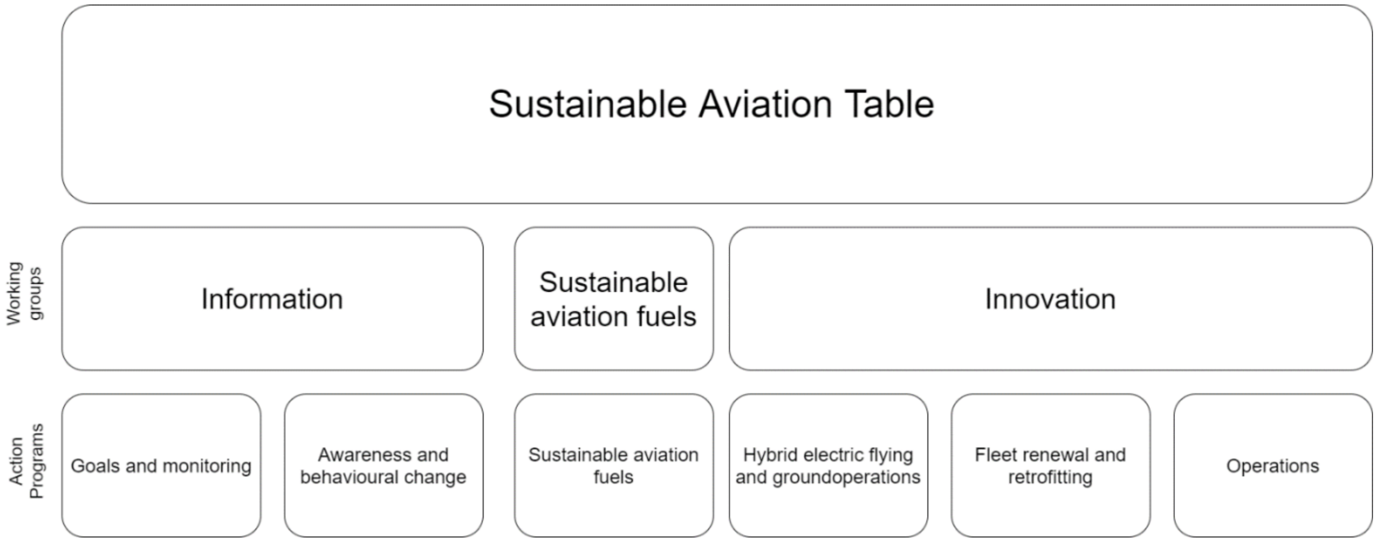

Figure 6, Structure Sustainable Aviation Table (SAT) (Duurzame Luchtvaarttafel, 2019)

4.2.2. International context interactions

This section shows what the international context is and how it interacts with the focal MIS. The focal MIS is the mission arena and overall MIS described in Section 4.2.1. The MIS described in this thesis is mainly focused on the Dutch innovation system. As the aviation sector is a global industry there is a discussion about who is accountable for aircraft emissions emitted beyond the borders of each state (ATAG, 2019). According to 12 interviewees, national abatement efforts are less effective than an international approach. Therefore, the European Commission (EC) and ICAO are the international organizations working on the policy for international aviation. The international context consists of those structural components (i.e. actors, networks and institutions) on a supranational or international scale affecting national policies. European and international agreements provide a supportive regulatory policy framework to achieve a level playing field. Besides these intergovernmental organizations, there are also large players within the industry. The large aircraft Original Equipment Manufacturers (OEMs), engine manufacturers, and global industry associations have strongly vested interests within the industry (Eriksson & Steenhuis, 2015). The interactions will become more evident in Section 4.3.

Figure 7 shows an overview of the different types of actors. Some actors in the international context have such a strong influence that they also cover the mission arena because they participate in the SAT. The size of each box is chosen arbitrarily and does therefore not mean one actor has more influence over another. There is a lot of overlap because many actors are both active in the mission arena and overall MIS. Actors are contributing both in the mission formulation and governance and also to the development, diffusion, and adaptation of innovative solutions. If an actor is closer to the core of the mission arena it means this actor has more power and has a larger contribution to legitimizing the mission's solutions. This presence has been determined via interview data, expert consultations, and literature review.

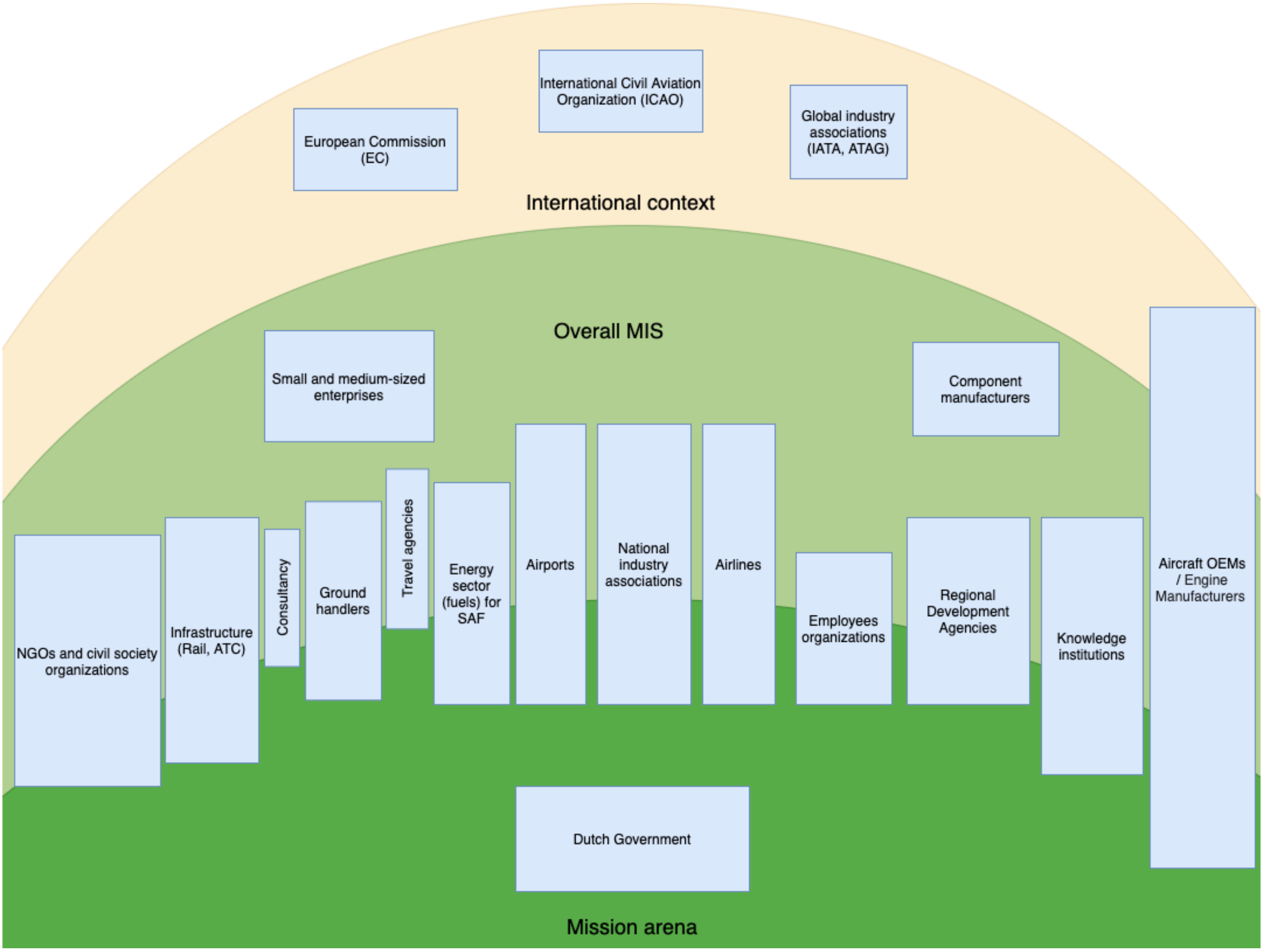

Figure 7, Actor categories in the mission arena, overall MIS and international context

4.2.3. Mission Governance Actions (MGAs) relevant to the mission

In this section, the different Mission Governance Actions (MGAs) are outlined and how they mobilize the structural components of the MIS. The impact of MGAs on the mission (and the identified barriers) is further evaluated in Section 4.5. For this thesis, many MGAs were identified in the mission arena. The government has created an effectiveness ladder to show what the contribution is of each policy instrument in terms of CO_2 reduction and its contribution to the energy transition (Figure 8). There are also two relevant MGAs initiated by the industry itself. Namely, the blending obligation for SAF and the Memorandum of Understanding (MoU) between two industry actors. In the second part, the international MGAs relevant to the mission on European and international levels will be explained and what their relationship is with the Dutch MGAs. A complete overview of all MGAs can be found in Appendix III.

Dutch Mission Governance Actions (MGAs)

Figure 8 shows an overview of implemented and planned mission policy by the government. The left side of the figure shows the CO_2-reduction targets, which have been elaborated on in the previous sections. The MGAs in this figure are the policy measures, which are divided into direct effects within the aviation sector, direct effects outside of the aviation sector, and uncertain indirect effects. These measures are necessary to support the development and diffusion of innovative solutions.

First, policy focusing on sustainable flying has direct effects. For example, the government is developing a policy framework for an initiative, which was at first initiated by the industry itself, for a blending obligation of 14% SAFs in 2030 (E4tech, 2019). For the upscaling of SAF, it is important to have sufficient facilities and infrastructure to produce the fuels. Currently, the limited supply and higher cost of SAF make tankering attractive. Tankering is uplifting extra kerosene in non-EU countries without a blending obligation. While this reduces costs for airlines it should be avoided as carbon emissions will increase and it also undermines the EU environmental objectives of the SAF mandate (ICCT, 2021). For technological innovation, several strategies are developed and implemented and enablers such as grants, and funding are available (Rijksoverheid, 2020a). For instance, the innovation strategy ensures that strategic choices are made by determining the level of development and the most important challenges for the innovation system at this moment. It strives for strategic choices to strengthen the long-term development and diffusing of innovation in the system (Rijksoverheid, 2020a). Other recently implemented instruments concerning technological innovation are mainly financial. These are grants for R&D and technology which were implemented in May 2021. Namely the *subsidieregeling R&D mobiliteitssectoren* (RDM) (subsidy scheme mobility sectors) and TopSector High Tech (TSH) *vliegtuigmaakindustrie* (aviation industry) which aim to stimulate research and development. There is also a *financieringsstrategie* (financing strategy) and a *groeifonds* (growth fund) planned and partly implemented for which interested parties in the aviation sector can apply for. The Memorandum of Understanding (MoU) between the Netherlands Aerospace Group (NAG) and Airbus is another MGA which is initiated by the industry. The purpose of the MoU is to create a long-term strategic relationship in the field of sustainable aviation research and innovation, for both academic and industrial parties (NAG, 2021).

Second, for direct effects outside the aviation sector, the government is focusing on enforcing the market-based measures for emissions trading and off-setting. Emission rights are traded through the market-based measure European Union Emissions Trading System (EU-ETS) and the market-based measure scheme for off-setting is Carbon Off-set and Reduction Scheme for International Aviation (CORSIA). The EU-ETS is a market-based measure to trade CO_2 rights economy-wide with other sectors based on a price per ton of CO_2, which is increasing over the years with a cap. To foster carbon-neutral growth, ICAO introduced a global market-based measure called CORSIA (Van der Sman et al., 2021). The objective of CORSIA is to stabilize growth of international after 2020 through the usage of internationals credits (ICAO, 2021). The average baseline emissions between 2019 and 2020 determine the offset requirements for the sector in a specific year (ICAO, 2021). However, this instrument is not that effective, as it is voluntary at the moment and its contribution is insufficient to contribute to the climate goals according to 7 interviewees. Both policy instruments are not as effective in the long term because they do not realize absolute carbon reductions within the sector, and eventually there remains no CO_2 left to compensate in other sectors.

Thirdly, for uncertain indirect effects, the government is focusing on alternatives to flying. In terms of alternatives to flying, awareness and behavioral change are discussed at the table for the working group information. Substitution by train is discussed in the action agenda Air/rail in which multiple stakeholders from the industry and government are involved in the selection of city pairs to replace short-haul flights (Rijksoverheid, 2020b). An aviation ticket tax is implemented since the beginning of 2021 (Rijksoverheid, 2020a). This financial instrument aims to create consumer awareness for the environmental impact of flying and aims to reduce price differences between other transportation modes. However, its impact to achieve the reduction targets is uncertain. Furthermore, there is a ticket tax to make the price differences between other transportation modes smaller. Both are also elaborated on in further detail in Section 4.1.2.

Lastly, another planned instrument is the *CO_2-plafond* (CO_2-ceiling) (

Figure 8). The status of this policy instrument is currently an ongoing discussion. The aim of this governance action is to oblige actors to reduce their emissions by setting a cap. One of the scenarios is that it enforces the aviation sector to degrow when the cap is reached. Consequently, this instrument is highly contested among actors in the mission arena, especially airlines and airports oppose as it would mean a likely reduction of flights and therefore resulting in reduced revenues if the targets cannot be met. According to one policymaker (PM2), "other countries have not yet announced such a far-reaching policy instrument to reduce their aviation emissions". However, 5 other interviewees state that a CO_2-ceiling would not be the most effective instrument to achieve carbon reductions, as this should be agreed upon internationally to keep a level playing field. These 5 interviewees also indicate that the market-based instruments EU-ETS/CORSIA are already in place serving as a market-based instrument to cap emissions. To conclude, its relationship with EU-ETS/CORSIA and impacts on legislation are still unclear and need to be researched.

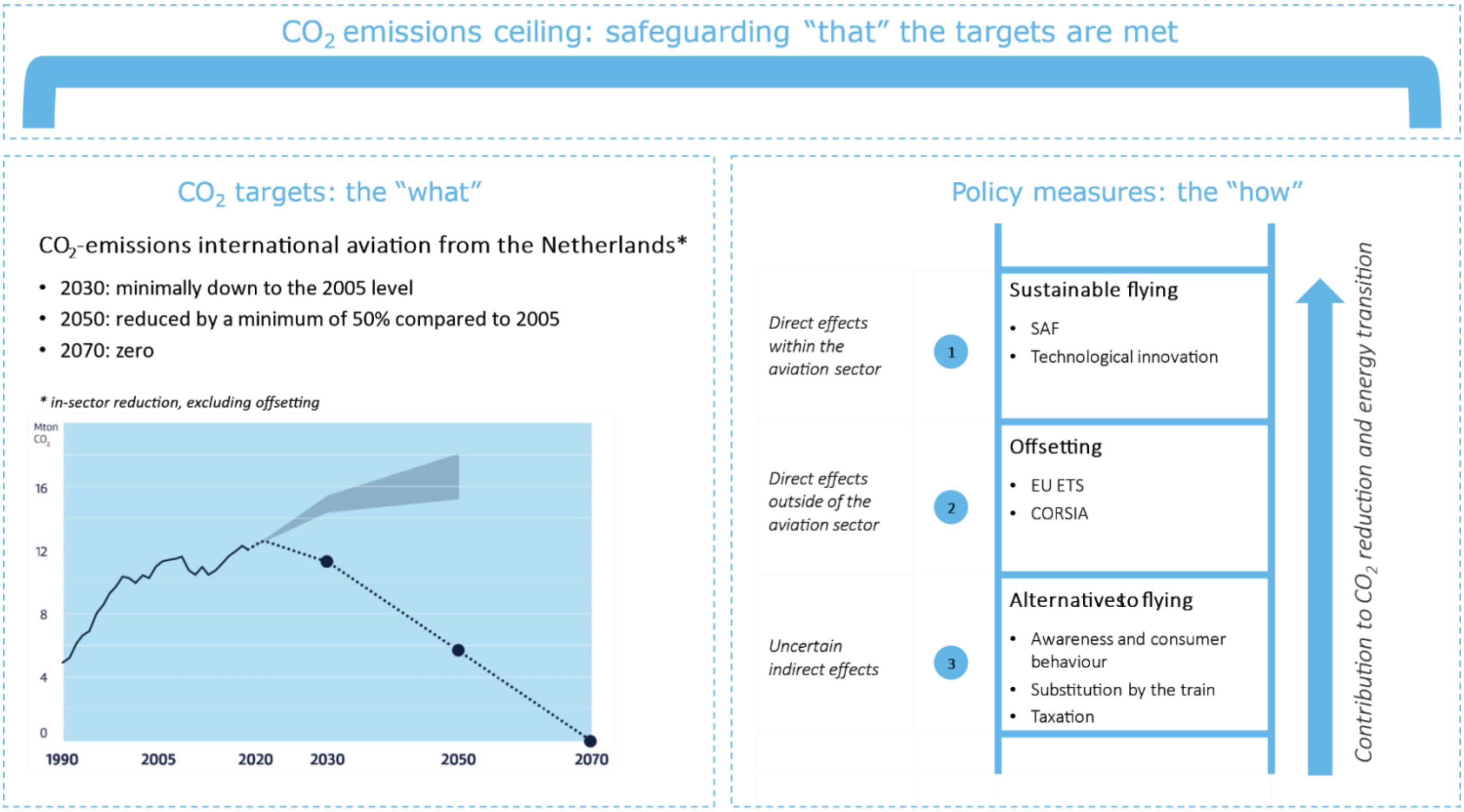

Figure 8, Effectiveness of policy instruments

International context Mission Governance Actions (MGAs)

Instruments initiated in the international context by the EU and ICAO are focusing mostly on the emissions from international aviation. The EU has introduced legislation packages for the European Green Deal. These *fit-for-55* (referring to 55% reduction in 2050) packages include regulations and guidelines for emission trading, renewable energy directives, and SAF blending obligations for aviation. According to 5 interviewees, a supportive European regulatory framework could foster the production of SAF and establish a level playing field between countries (EC, 2019). The EU is already working on the ReFuelEU initiative and the Renewable Energy Directive II (RED) for further implementation of SAF (EC, 2019). The EU has also announced a blending obligation of 5% SAF in 2030, however it is less ambitious than the Dutch 14% (ICCT, 2021; EC, 2021). In 2050 the EU has proposed a SAF blending obligation of 63% (EC, 2021). Also, the EU has announced a tax on kerosene of 33 cents/liter (EC, 2021). This is an ongoing debate to further discourage the use of fossil fuels. Furthermore, the Clean Sky research program is contributing to innovation in the aviation sector with R&D funding for SMEs, industry members, universities and research facilities (Clean Sky, 2021). The UN-organization ICAO has also introduced policy, for instance, a CO_2 standard, and develops State Actions Plans (SAP) and the beforementioned LTAG to foster international carbon reduction in a level-playing field (Transport and Environment, 2016; ICAO, 2020). It is expected that at the ICAO assembly in 2022 new agreements are made concerning carbon reduction in aviation (ICAO, 2019).

4.3. System functions analysis

The spider diagram below (Figure 9) shows the outcome of the system function analysis consisting of 32 interviews. Some interviewees did not provide a score on all system functions, which is why some lines are missing or interrupted in the diagram. The strengths, weaknesses, and barriers of each system function are analyzed in this section. The functions SF1, SF4A, SF5A, SF6A, SF6B, and SF7 show a larger variance in scoring by different actor categories. The reasons why actors share a different vision about fulfillment will be discussed.

Figure 9, System function fulfillment

4.3.1. Entrepreneurial activities (SF1)

Entrepreneurial activity is rated with an average score of 3,07 (N=29; σ=1,04) which is neutral. 17 interviewees indicate that there is a lot of entrepreneurial activity going on. 9 interviewees state that there is a high willingness in the Dutch aviation sector to participate in experiments and start-ups. Literature confirms that numerous start-ups in the Netherlands are developing innovative solutions to make aircraft more fuel-efficient for cost and emission savings (Broekel & Boschma, 2011). Aircraft (component) manufacturers, fuel producers, knowledge institutes, and universities show a lot of activity in the sector (AL2, UV1, KI3, PM4). One policymaker (PM4) states that in terms of entrepreneurial activity the fuel companies are doing excellent: "they are like a kind of catalyst, serving as an example for the sector and government by creating legitimacy on both national and European level for sustainable aviation". Yet, 5 interviewees indicate that the amount of entrepreneurial activity at this moment is not adequate to achieve the carbon reduction targets. This is also shown by the variance in scoring between actors. Universities and the interviewed entrepreneur believe this function is weakly fulfilled. 11 interviewees also state that the levels of knowledge development, knowledge exchange, market formation, and resources are currently inadequate to facilitate experiments and entrepreneurial activities. The barriers encountered in the Dutch innovation system that prevent success are caused by 1) large aircraft manufacturers forming a duopoly; 2) strict safety regulations and certification processes; 3) capital intensive high technology and 4) long lead times making it a time consuming and costly process especially for start-ups and SMEs. These barriers also interrelate with other SFs which will be explained in Section 4.4.

First, interviewees indicate that the aviation industry is dominated by two large Original Equipment Manufacturers (OEMs) of narrow- and wide-body civilian aircraft (9 interviewees). At the moment, these OEMs have a very large backlog of thousands of aircraft worth more than 100 million USD each which will be delivered in the upcoming years. There is an enormous vested (financial) interest in the production facilities and therefore "there is, in general, a low incentive to invest in new aircraft designs in the short term" (UV2). As a result, this duopoly creates barriers to enter the market for start-ups and SMEs (UV1, OM2). As one interviewee states: "the Netherlands has a relatively large aviation industry but is marginal in comparison to other countries. Countries such as France, the UK, Spain, and Germany are more involved in the production. If you want to develop components, you want to be in the OEM's supply chain" (OM2). According to 5 interviewees, the large aircraft manufacturers determine which initiatives are considered interesting to follow up and to invest in but "small players definitely play a key role in shaking things up" (IA5). While the two large OEMs are experimenting with alternative aircraft designs on larger aircraft, interviewees indicate that most entrepreneurial activities are not taking place in this large commercial aircraft market but with smaller aircraft, the so-called general aviation (GA). As OM2 states: "if a regional government in the Netherlands wants to stimulate new technologies to achieve targets. Well, we all do not want to wait until Airbus is going to ask the ecosystem to produce technologies, or if airlines are going to ask Airbus themselves for new technologies. To break through this lock-in, you need a push, and the Netherlands is currently absolutely not ready to participate in this process". Yet, many experiments are taking place on aerodynamics and on alternative propulsion such as using hydrogen and battery-powered aircraft with for example the retrofitting of a six-seater turboprop aircraft with hydrogen fuel cells. There is already a full operational two-seater electric airplane available on the market today (EN1).

Secondly, throughout the history of aviation safety has been a boundary condition for its activities. Even if there is a minor risk of a catastrophic outcome, components need to be redesigned or adjusted (Moir & Seabridge, 2012). Many avionics and systems are multiple redundant in a dissimilar way, which means that two, three, or sometimes even four systems each differently designed are on stand-by in case of a failure (Moir & Seabridge, 2012). These very strict safety regulations and certification processes take in general a long time to go through and bear very high costs according to 7 interviewees and literature (Moir & Seabridge, 2012). It takes about 10 billion euros and 10 years to fully develop an aircraft from scratch until the first aircraft is delivered, and for disruptive designs, even more time is necessary to overcome technological challenges according to 5 interviewees (see also Appendix II) (Peeters & Melkert, 2021). As one interviewee (OM2) states: "for a small innovation in the aviation sector you need at least 3 to 5 years and if it is bigger (i.e. a large component) you are 7 years working on that innovation before it can be (commercially) applied". 8 interviewees also indicate that there needs to be more room for experimentation such as demonstration facilities and pilot projects.

Thirdly, the aviation sector is a high technology sector that requires a lot of cutting-edge knowledge (SF2) and human- and financial resources (SF6). There are a lot of interdependencies between different parts, and each part needs to be certified before it can be applied. As OM2 states: "in an Airbus A380 there are about 6 million parts. 6 million parts delivered by numerous suppliers, which makes it so complex and inherently difficult to develop new, sustainable, innovations. The OEM prefers working with large suppliers as there are thousands of suppliers, each delivering parts of (sub)components".

This all boils down to the fourth point, which is about the required financial capital for innovation in the aviation industry. To develop a fully commercial aircraft there are numerous processes for (safety) certification, knowledge, and financial requirements for cutting-edge technology and a competitive environment dominated by a duopoly. As one interviewee mentions "we are waiting for a Tesla moment in aviation, like Elon Musk shaking things up in the automotive industry" (RD1).

4.3.2. Knowledge development (SF2)

Knowledge development is divided into the development of knowledge that contributes to achieving the mission (2a) and knowledge to unlearn practices that are harmful to the mission (2b). Interviewees rated SF2a with an average score of 3,33 (N=30, σ=0,77) which is neutral. SF2b was rated with an average score of 3,00 (N=30, σ=0,92) which is neutral as well. The knowledge development is strong in this "very dynamic industry with lots of innovation and typically leading-edge technologies" (PM3). Other interviewees also indicate that there is a strong aviation knowledge development infrastructure in the Netherlands (KI2, IA3, UV1). From a historical perspective, the Netherlands has a large high-tech aviation industry with a lot of knowledge across airlines, companies, manufactures, universities, and research institutes (6 interviewees). However, the knowledge at this moment is not adequate to bring the necessary incremental and radical innovations into commercial application. 8 interviewees indicate that there first needs to be more demand in market formation (SF5) before knowledge will be further developed into commercial applications. Regulations and stimulation for innovation could create a demand for solutions and therefore accelerate knowledge development. Another interviewee (OM2) states: "if we would decide not to focus on innovation but to import it (sustainable solutions) from other countries, that could be a choice, but yes, in that case, you should not focus on your ecosystem anymore". According to several interviewees, this would result in less economic activity and a lower willingness of foreign investors to invest in the Dutch economy (IA2, OM2, KI3). Eventually, knowledge development would decline at universities and knowledge institutes in the Netherlands as there is no demand for knowledge anymore (OM2).

Other interviewees (NG1, NG2, KI1, KI2, UV2) state that there is sufficient knowledge about the social innovative solutions but that for instance influencing consumer behavior could be integrated more into the policy (KI1). As one knowledge institute (KI1) states: "the starting point is often to reduce CO_2 without having to change the system. So, without influencing people's behavior too much (…) politicians keep a lot of distance discussing that topic". Furthermore, for knowledge development to phase out practices harmful to the mission, 5 interviewees did not see a distinction between the two types of knowledge development because there are no alternatives available yet. One interviewee (KI4) puts this as: "look, the alternatives are not available yet. So, it is hard to phase something out at this moment. Then you would be talking about less flying before you can fly more again in the future. I don't know if that is going to happen or if that situation is desirable". Other interviewees indicate that more knowledge development on enabling processes to support the transition could accelerate the phase-out of harmful processes (IA4, OM2).

4.3.3. Knowledge diffusion (SF3)

Interviewees rate knowledge diffusion with an average score of 3,09 (N=31, σ=0,87) which is neutral. In the Dutch innovation ecosystem, a lot of knowledge exchange among actors is taking place, especially on the subsystem level (9 interviewees). Knowledge institutes, the industry, and the government are working together and diffuse knowledge through networks, seminars, conferences, and platforms (6 interviewees). The SAT is an example of such a platform where the sector and government are diffusing knowledge. Interviewees indicate that since the SAA has been signed, more and more knowledge about sustainable aviation is being diffused among actors (5 interviewees). As AP1 states: "the action plan smart and sustainable and the sustainable aviation agreement are both contributing a lot to knowledge development and how knowledge is communicated and spread. This also increases the awareness among actors".

An identified barrier concerns the diffusion across the value chain. As one airport (AP1) puts it: "actors at the end of the (value)chain do not always know what is happening at the beginning of the chain, while everybody needs each other to get there". Another barrier mentioned by 7 interviews, is that actors participating at the table are focusing too much on knowledge within national borders. The government, industry, and research institutes should share more knowledge and cooperate on European and international levels because the "challenge of climate change is too big to do on your own" (OM3). Besides, a focus on cross-sectorial knowledge exchange (RD2, PM4, UV2, IA1) and valorization of knowledge from knowledge institutes and universities (KI3, IA4) are mentioned as insufficient. Other barriers mentioned are about actors not willing to share knowledge due to the high cost of investment (see SF1) and intellectual property rights (5 interviewees). Also, information and figures of what emissions are caused by aviation and what contributions are necessary should be organized so that everybody is working with the same facts and figures (5 interviewees).

4.3.4. Problem directionality (SF4a)

Problem directionality is rated on average a 3,35 (N=31, σ=1,02) which is neutral. All interviewees agree that sustainability is an important topic, and 25 interviewees state that sustainability has gained a higher priority on their agenda over the last decade and especially since the last few years after the SAA has been signed and since the SAT was established. As mentioned before, safety is a boundary condition in aviation and has, therefore, according to 18 interviewees, a higher priority than sustainability. Another interviewee (OM2) states that "95% of what is mentioned in the policy memorandum is about aircraft operations". The policy memorandum could have emphasized more on sustainability and is according to one policymaker (PM1) a "missed opportunity when it is about forming a vision towards the future concerning sustainability". For the survival of aviation in a sustainable future, sustainability must be treated more as a boundary condition and not as an accessory as it is right now. Sustainability should be more integrated into policy according to 5 interviewees. The memorandum is "mostly about the ongoing operation of aircraft, airports and airlines and less about how sustainable innovations can be brought into the system" (OM1). This also manifests itself in a strong variance in the scoring of this function caused by different perceptions of types of actors. The NGO/civil society organizations and fuel companies state that the priority for sustainability needs to be higher, while universities and airports state that it is already very high at this moment.

While in the Netherlands there is contestation about the level of priority for sustainability, globally there is according to 6 interviewees even less priority for sustainable aviation. According to these 6 interviewees, other countries put more emphasis on economic growth and connectivity. One policymaker (PM2) perceives this as the strongest bottleneck for effective international climate policy and states: "if it is about for example accepting that the economic benefits of aviation are maybe less important than sustainability. Well, if I start talking about that I get the feeling they see me as a fool. Like for most countries in ICAO, economic growth is what it was for us (the Netherlands) in the 70s, 80s, and 90s: a vehicle for growth and development for the freedom of people to increase their welfare. This interest is much more important for those countries in every discussion about sustainability". This makes it hard to negotiate on an international level, as other countries also want to develop their economies. (Gössling & Upham, 2009). According to multiple interviewees (PM2, IA2, IA3, PM4), this also affects the creation of effective national policy negatively and therefore forms a barrier to create a strong regulatory framework on European and international levels.

Another barrier mentioned by 17 interviewees is that the functioning of the SAT at this moment is inadequate to achieve the reduction targets. 5 interviewees mention that the SAT has a lot of potential to book progress and carry out ambitions to achieve the reduction targets. The SAT was initiated as a negotiation table for the SAA in 2018. After this phase, the table has not yet evolved into an executive table, where the contents of the agreement are translated into actionable points. The result is a low commitment among those actors in the industry that develop and diffuse innovations as there is a lack of long-term focus. This barrier is also interrelated to SF4b, where a long-term supportive policy framework is lacking. It also touches upon an interrelated barrier with SF4c, where inadequate coordination efforts are discussed, and SF7 where a large variance in legitimacy and resistance between society, sector, and the government also result in a low commitment.

4.3.5. Solution directionality (SF4b)

Interviewees rate the solution-directionality with an average of 3,14 (N=32, σ=0,94) which is neutral. 9 interviewees indicate there is in general consensus among actors what climate policy for aviation entails and which technological and social solutions there are possible to achieve the reduction targets (see Appendix II – Technological and social solutions). However, there are differences in opinion on which solutions should be prioritized. In the short term, 5 interviewees indicate that the usage of SAF is the most feasible sustainable solution to keep up with the growth of the aviation sector, while still be able to comply with CO_2 reductions. One policymaker (PM1) states: "it is not clear what solutions for the long-term we are going for right now. The point is, you can say after 20-25 years whether something has been successful in aviation. Focusing on electrical flying is a good thing for small aviation, but over large distances, it is not going to happen anytime soon. You can invest one time, and what are you going to invest in? Flying 300 people to Antalya (Turkey) electric is not going to happen I think". Electric aircraft powered by batteries are too heavy for application on large scale, and battery technology improvement will not make up for that difference anytime soon (Peeters & Melkert, 2021).

For another barrier, 6 interviewees indicate that a long-term supportive policy framework that focuses on the development and upscaling of solutions is missing. At this moment there are no assurances for the MGAs as there is no legislation or regulatory framework. This also touches upon what has been said for SF4a (problem directionality) as it causes a low commitment and willingness from actors to participate in innovation without having these assurances. 10 interviewees indicate that a supportive policy framework is necessary to accelerate knowledge development and entrepreneurial activities to make the market more attractive for sustainable solutions.

As shown in Appendix I, there are short, medium, and long-term solutions. The government policy is mainly focused on SAF and innovations as these would have the most effect on CO_2 reduction within the sector (see Figure 8). 14 interviewees indicate that they agree with this policy framework while 5 other interviewees state that there should be more focus on the alternatives to flying and behavioral change. As NGO1 state: "we turn it (Figure 8) 180 degrees around. First, you are talking about how to reduce demand? So, start with a hard cap on CO_2 that ensures carbon reduction in the industry, and if that is not enough you can start pricing with an aviation tax or a tax on kerosine, and also use EU-ETS. And then you are going to look at flights, how can I make them as clean as possible? Technology will be at the bottom of the figure, and you need to do it parallel". Other interviewees also question the solution directionality, as UV2 states: 'do we really need to fly far destinations and multiple times a year? Maybe we can just be close to home for a holiday or we can work online".

In short term, there are small benefits in terms of carbon reduction from ATM and aircraft operations to be expected (Van der Sman et al., 2021). 5 interviewees indicate there is too much focus and too many resources are allocated to these solutions. Knowledge institutes and universities are paying too much attention as one policymaker (PM4) indicates: "at the European level there is a jar of money and grosso modo half of these billions is dedicated to ATM research. For climate, ATM is not even a drop in the ocean but is keeps recurring". As KI1 indicates when ATM is optimized: "airlines do not need to change their business model, so they save fuel and therefore cost and could even fly more often because routes are shortened, and flight times are reduced."

Also, according to 6 interviewees there is among NGO's and civil society organizations a strong focus on substitution by train. While substitution by train reduces emissions, it is insufficient to make large reductions possible (see Section 4.1.2). A higher level of reduction can be achieved by reducing long-distance flights. As shown in Figure 10 roughly 50% of the fuel is used during 90% of flights which have on average a total distance below 3000 km and the other 50% is used during 10% of the flights which have an average total distance above 3000 km. The so-called ultra-long-haul flights above 8000 km make up for 1% of the flights and use 20% of the total amount of fuel used on all flights together. Obviously, these flights cannot be substituted by train so a strong focus on substitution by train has only a limited contribution and it requires a lot of effort and resources to reduce those 90% of flights. Therefore, 5 interviewees indicate that there should be a stronger focus on those solutions that do contribute such as reducing those ultra-long-haul flights.

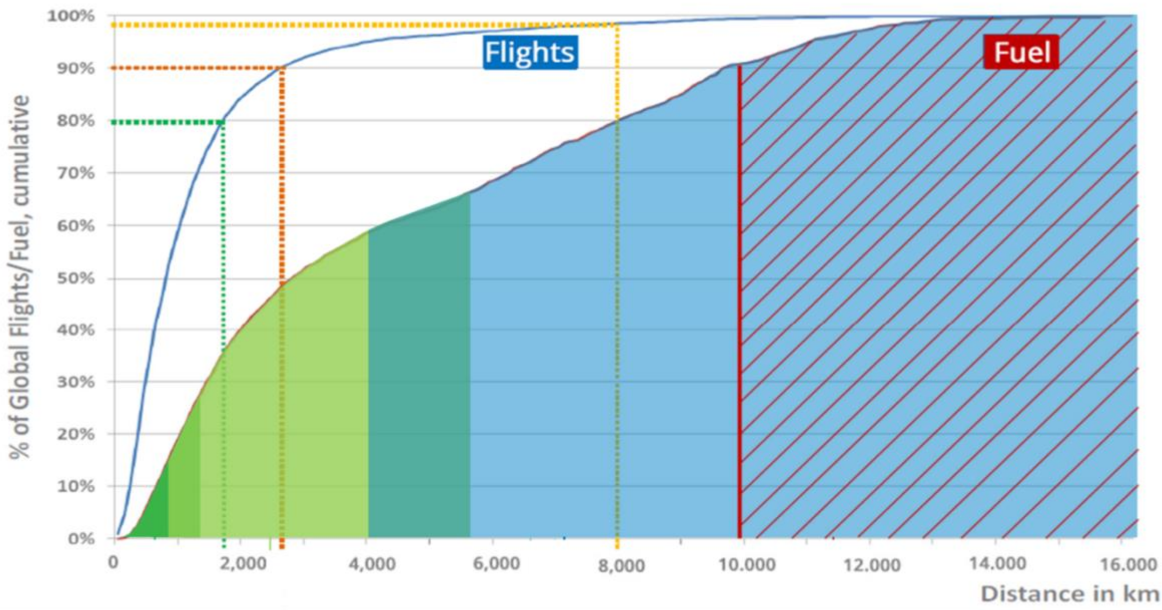

Figure 10, Cumulative fuel usage compared to flight distance (Fokker GKN, 2019)

4.3.6. Reflexivity (SF4c)

Reflexivity is rated on average a 2,17 (N=27, σ=0,79) which is bad. The majority of interviewees (17 out of 32) agree that there is at this stage no mechanism in place that can sufficiently evaluate, anticipate and redirect the mission. Especially the anticipation and redirection of the mission are indicated by 5 interviewees as insufficient. Monitoring is taking place according to 6 interviewees because fuel usage figures and therefore CO_2 emissions are recorded by each airline to comply to the EU-ETS regulations. Reflexive governance is both in the mission arena and overall MIS low. One interviewee (PM1) says "we have just started, so there is not much to redirect yet". Another interviewee (KI4) indicates that "measuring yearly our progress has no use. When disruptive innovations in about 10-15 years enter the market, aviation will be sustainable. Otherwise, you are reporting each year and saying there is no progress... yes that is because it takes time to develop new technologies". However, monitoring the progress of for instance the TRL of technologies might be useful to indicate whether the mission is on track to meet its targets (Van der Sman et al., 2021). Other interviewees (4) indicate that missing reflexive governance lowers the commitment and willingness to participate as there is no long-term vision. 3 interviewees (KI4, IA2, PM3) indicate that in the future the inclusion of non-CO_2 emissions might result in more stringent reduction targets. 5 interviewees doubt whether the actors are well aware of the consequences as it seems like 'the elephant in the room' (IA3) if more drastic measures need to be taken to reduce emissions.

The CO_2-ceiling is according to 8 interviewees a strong policy instrument depending on what the obligations for actors are going to be and what the consequences are when the cap is reached. The airline and airport infrastructure are according to IA1 'too big to fail' and would result in a gap in infrastructure causing economic damage. "We should focus on how to achieve the CO_2 targets instead of readjusting policy in case the ceiling is passed" (IA1). Other interviewees (PM1, OM2) state that corona has a very large impact on the industry as "some say this is another lost decade (after the financial crisis) and the focus is mainly on recovery. The question is whether policymakers dare to take measures if the targets are not being met" (OM2).

Furthermore, according to 5 interviewees, the SAT needs to evolve from a negotiation table into an executive table to provide more coordination. This also touches upon an interrelated barrier with SF4a, where this results in a low commitment from actors involved in the development of innovations. 6 interviewees indicate that coordination among actors participating in the SAT is not adequate. As one fuel company (FC2) puts it "everybody is starting to make a run for it without coordinating. Because of that, you get problems along the way". These problems entail a not optimal functioning governance due to the matter of who is accountable and responsible (FC1, AP1). This is shown by the fact that there is no clear coordination of who is responsible for what activity and who is in the lead and who is accountable (IA2, GH1). To overcome this barrier, the SAT needs to be more coordinative, and action-oriented according to 7 interviewees. Strong governance with the focus on a long-term, central, steering to execute actions is missing according to 5 interviewees.

4.3.7. Market formation and destabilization (SF5)

Market formation (5a) is rated on average a 2,60 (N=31, σ=1,10) which is neutral. Interviewees rated market destabilization (5b) on average a 2,03 (N=30, σ=0,74) which is bad. Market formation is low since there is no sufficient demand yet for sustainable alternatives (12 interviewees). A large variance in scoring is found among industry associations and fuel companies, which are the producers of innovative solutions while airports and airlines are further down the value chain as user of the product. Producers are awaiting policy and financial support, while users are waiting for the product to enter the market. This chicken-and-egg metaphor creates a situation where there is also no incentive to develop innovations (see SF1 and SF4b). As one interviewee (AL1) states: "I think maybe we should have a form of industry politics in the Netherlands, where the government is actively intervening with business' activities instead of only regulating". According to 5 other interviewees the government should take more control as actors have financial and economic interests at stake (OM2) and might therefore be unwilling to make the necessary compromises (KI1). Another interviewee (OM2) states: "the SAT is a very good tool to make it possible to foster innovation in the Netherlands but needs to realize it can only assert influence to a certain extend on system or subsystem component level as there are no OEMs in the Netherlands". 7 other interviewees indicate that new technologies also need to be profitable enough before upscaling.

The government can steer innovation to initiate a technology push, but also on the European level, mandatory policies could stimulate innovation for the large OEMs according to 6 interviewees. Another interviewee (IA3) states that governments are slow "because it's like trying to, you know, turn around a supertanker. It takes a long time to turn a government around usually. And when they try and do things fast, often they get it wrong and can have some unintended consequences. So, it is important for the industry to be leading in that sense, but for us to have the support where we need it through government intervention in the right way". According to 5 interviewees, the government can be very normative, but more stimulations can also foster the development of innovations (see SF6 below). In terms of market formation and upscaling for SAF there needs to be a stronger policy framework as well: "I think that's a great example of in the last 10 years, we haven't really achieved much in terms of the penetration of sustainable aviation fuels into the aviation market, because there hasn't been the long-term policy framework that really stimulates the market and supports the entrepreneurs to bring that forward and for it to be taken up by the aviation sector" (PM3).

23 interviewees indicate that there is not much destabilization taking place at the moment. The aviation tax is a financial instrument used as an environmental tax to discourage traveling by airplane but according to 11 interviewees, it has no effect in its current form. As PM2 puts it "because aviation tax as it is right now, does contribute zero point zero towards climate goals. Aviation tax an environmental tax is a complete nonsense, it has been drafted as a financial instrument". Other interviewees (OM1, PM1) indicate that the destabilization of the market incentivizes new technologies to be pushed through as current markets are moving away from harmful practices. However, destabilization is currently badly fulfilled as there are no alternatives applicable at full scale to make aviation more sustainable. Smart taxes and grants are examples of destabilizing policies, while also existing tax exemptions on for instance kerosine should be removed (5 interviewees) (Peeters, 2019).

4.3.8. Resource (re)allocation (SF6)

The system function resource allocation (6a) is rated on average a 2,70 (N=30, σ=1,25) which is neutral and resource reallocation a 2,48 (N=26, σ=1,34) which is bad. There is a large variance in scoring because some actors have more resources available than others and therefore give a different score based on their situation. The OEMs, fuel companies, and the interviewed ground handling company indicate that they have sufficient resources (financial, human knowledge, and materials) to contribute to the mission. One OEM (OM1) endorses this: "key players such as (two large company names) ask for money and guidance by the government, but they can also act by themselves". At the same time, one policymaker (PM1) states: "the government invests in the innovation in other industry sectors, but not in the aviation industry". 15 interviewees indicate that other countries have a higher innovation budget for aviation. As one OEM (OM2) states: "in every country around us there are a lot of investments in sustainable technologies, also in aviation, but in the Netherlands actually not that much".

Secondly, as shown in SF5 there is no demand in the market yet for innovations. The other 25 interviewees indicate that amongst other parties in the aviation sector fewer resources are available for innovation at this moment or that they first want, according to 8 interviewees, more long-term assurances before investing. As shown in SF1, there are a lot of financial resources required in this high-tech sector for the full development of a commercial aircraft, and a lot of uncertainty needs to be overcome according to 5 interviewees.

Another barrier mentioned is the scarcity and competition over resources. For the production of synthetic aviation fuel, large quantities of hydrogen are necessary, while other sectors also need hydrogen as green energy for their carbon reductions (7 interviewees). There needs to be upscaling of production capacity for hydrogen and e-fuels while at the same time there is competition with other sectors. Besides sectors such as road transport can use batteries easier than aviation due to weight issues, and biofuels can better be used in aviation to replace kerosene (Peeters & Melkert, 2021). This means an allocation of resources between sectors is something that requires more attention (8 interviewees). Another industry association (IA4) indicates that airlines are facing a dilemma: "There will be a time at which an airline is going to have to make a decision, though, as to what kind of aircraft they want to invest in or what kind of aircraft they're going to buy. Because you have got a lot of airlines that will stop having fleets that are ready to retire. They will need to be replaced. Do they replace that with a new conventional aircraft? Do they wait for an extra couple of years, while using older aircraft that are a bit more polluting and wait for a hydrogen aircraft to come along? Hopefully, it does. But there's a lot of decisions that need to be made in the next 10 years or so".

Resource reallocation was rated lower by interviewees, and a strong variance can be seen. 9 interviewees indicate that there are in general already fewer resources available for innovation. Therefore, no resources are remaining to be reallocated. Fuel companies, the ground handling company, and aircraft OEMs (7 interviewees) stated that resources do not need to reallocate as their business models are oriented towards SAF (FC1, FC2) and OEMs stated that most of their budget is already invested in making aircraft more fuel-efficient. Two OEMs (OM2, OM3) mentioned optimization processes such as using less and more environmentally friendly materials. 14 other interviewees stated that a reallocation of resources is only possible when there is an alternative. Fuel burn is the main cause of carbon emissions as indicated by 5 interviewees. As KI1 puts it: "first an alternative for kerosine is necessary otherwise the only other option is a reduction of flights".

4.3.9. Creation of legitimacy and counteracting resistance to change (SF7)

This system function is rated on average a 3,26 (N=31, σ=1,05) which is neutral. There seems to be in general more legitimacy and less resistance towards sustainable solutions for aviation. However, there is a strong variance in scoring among the sector, society, and the government. These differences in resistance and legitimacy also result in a lower commitment to participate in innovation as shown in SF4a. 5 Interviewees indicate that there is distrust from society towards the aviation sector and government caused by strong disagreement over the past decades about noise pollution around airports and surrounding cities where fly routes are located (Rijksoverheid, 2020a). As civil society and NGOs are mainly advocating for less flying to reduce the environmental damage caused by aviation, there is an advocacy to put a stronger focus on social innovations according to 6 interviewees. For instance, substitution by train, 'smart' taxes and less flying (Peeters, 2019). The industry sector argues that there needs to be more dialogue about the negative effects as OM1 states: "be more serious about what really needs to be done and talk about it". As OM2 states: "some politicians argue that flying has to be reduced without doubt and that this (a reduction) is the only solution. There is a strong resistance against innovation or let alone a technological explanation why something is or is not possible. It doesn't land when discussing it with those parties". 5 other interviewees indicate that actors need to focus on interests rather than points of view. As AL1 state: "when comparing the Netherlands with other countries around us we have a very tight innovation budget. So yeah, the trust among actors to take sustainability seriously is just not there. Because of that, actors are less willing to show initiative and step-up front. Actors do not believe that the Netherlands can be a front-runner. Yes, that is missing right now".

4.4. Systemic barriers analysis

The system function analysis revealed that there are many barriers. At this moment, no system function is scoring 'good' or 'excellent'. This section aims to understand what the root causes are from the identified barriers. These root causes are stemming from those barriers that hamper the innovation system to be more successful in developing and diffusing innovations (Hekkert et al., 2020). In this section, a distinction is made for the barriers and weak fulfilled system functions in the mission arena, overall MIS, and international context (see Figure 12 below). The analysis resulted in the identification of three networks of pressing systemic barriers and their corresponding weak system function(s). The next sections will discuss each set of systemic problems in more detail, supported by flow charts to visualize their relationship. The boxes in orange are barriers related to the system functions and the yellow ovals are the weakly fulfilled system functions caused by those barriers.

4.4.1. Missing long-term central steering of the mission

The first set of systemic problems are regarding a low commitment by industry actors and a missing long-term policy framework that provides central steering to execute the mission. The barriers are mainly stemming from SF4a (problem directionality), SF4b (solution directionality), SF4c (reflexivity), and SF7 (creation of legitimacy and counteracting resistance to change) and are interrelated with SF5 (market formation) and SF1 (entrepreneurial activities). The systemic problems are caused by weak reflexive governance (SF4c) and a large variance in legitimacy and resistance between society, sector, and government (SF7). Figure 11 shows the interrelatedness of these barriers. The number between brackets in the paragraphs below are a reference to this figure.

Firstly, the missing central steering to execute the mission that provides a long-term policy framework is caused by multiple systemic problems. The first barrier (1) is the inadequate functioning of the SAT to achieve the reduction targets. At first, the SAT was initiated as a negotiation table, but the table has not yet evolved into an executive table. The contents of the SAA need to be translated into actionable points to provide a long-term supportive policy framework. The SAT needs to be more action oriented. Strong governance with the focus on a central execution for actions is missing. For instance, is the SAT an advisory body or does it also have decision-making powers?

Secondly, two systemic problems result in weak reflexive governance to evaluate or redirect the mission (SF4c) (2). One barrier (3) is about missing monitoring and evaluation tools to report mission progress since there is no active evaluation and redirection strategy for the mission yet. 4 interviewees indicate that a missing reflexive governance lowers the willingness to participate in innovation because there are no clearly defined actions to monitor, evaluate or to anticipate on. The second barrier (4) is about inadequate coordination efforts which are not undertaken about who is responsible and who is accountable. This barrier is closely related to the first barrier. However, the difference is that this is more about the coordination among actors in terms of who is fulfilling what role and who is in the lead. The weak reflexive governance is creating a loop because it is reinforcing the missing central steering.

Thirdly, a low commitment by the industry actors is caused by a barrier (5) in SF7 about a large variance in legitimacy and resistance between society, sector, and government. These differences in resistance and legitimacy result in a lower commitment to participate in innovation. These industry actors are mainly involved in experimentation with (disruptive) technologies. Currently, there is a strong focus on technological innovation and less on social innovation, which contributes to the large variance in legitimacy and resistance between society, sector and government (SF7).

As a result, a long-term supportive policy framework is lacking as it is not established yet (6). At this moment there are no assurances to carry out the planned MGAs as there is no legislation or regulatory framework. A supportive policy framework is necessary to accelerate experimentation (SF1) (7) and to make the market more attractive for the upscaling of sustainable solutions such as SAFs (SF5) (8). The missing policy framework also reinforces the low commitment among those actors in the industry that develop and diffuse innovation. Because of these missing assurances they are careful to participate due to the high financial investments involved. Also, since there are no alternatives available yet, there is a weak market formation and destabilization (SF5). The loop is closed, resulting in a reinforcing effect of inaction if no governance actions are undertaken.

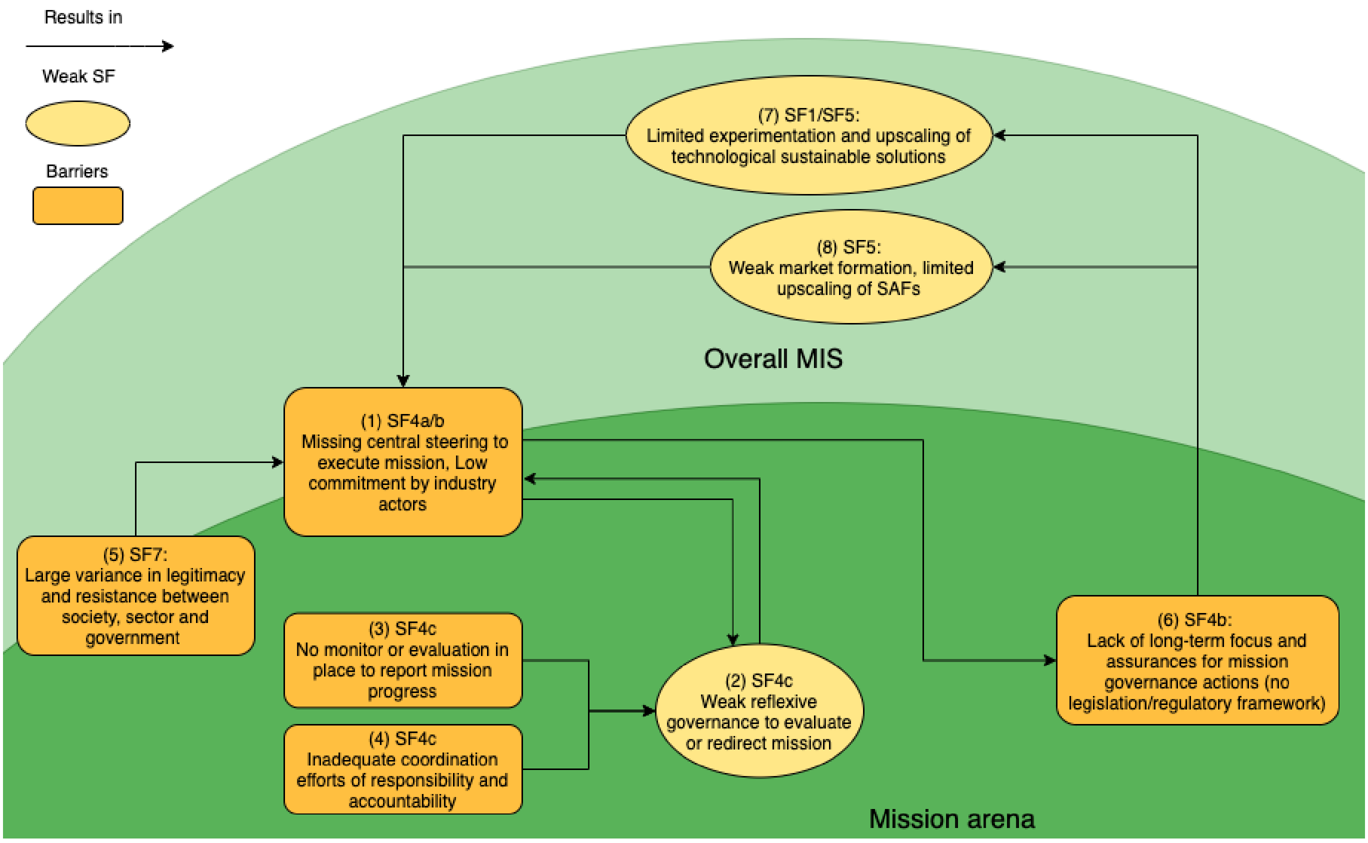

Figure 11, Interrelatedness barriers governance sustainable aviation (the numbers refer to the text)

4.4.2. No upscaling support for Sustainable Aviation Fuels (SAFs)

The second set of interrelated systemic barriers is regarding the upscaling support for SAFs (Figure 12). The number between brackets is a reference to the figure. A lack of long-term supportive policy (6) affects the market formation (8) (SF5) as there are no sufficient production facilities for SAF yet. This weak market formation is caused by the fact that fuel producers do not have a supportive policy framework to produce the fuel and assurances that there is a market, while the users (airlines) are demanding fuel but cannot be supplied because it is not available. Airlines want to use the fuel when it is available, but they also indicate they have a reluctancy to carry the price differences compared to fossil kerosene for competitive reasons. While this would eventually result in a higher ticket price for the consumer, there needs to be a level playing field to avoid unfair competition with other countries. This lack of stable policy for the long-term makes it unattractive to upscale this market for both the fuel producers and the airlines. A lack of alternatives to SAFs results in a reinforcing loop to the identified governance barrier (1), which in its turn results in a low commitment by industry actors.

From an international perspective (EU/ICAO), there is a weak regulatory framework (9). This is caused by a lower priority for sustainability by some other nations (10). These nations are prioritizing economic development over a sustainable aviation sector as indicated by 6 interviewees. These countries see aviation as a vehicle to growth and are therefore reluctant to participate and invest in more expensive sustainable alternatives. Therefore, it is important to convince these nations in order to create a level playing field otherwise policies are less effective. For example, airlines could be deviating to other countries to fuel their aircraft, which is called tankering (see Section 4.2.3).

4.4.3. Missing policy framework for incremental and disruptive technological innovations

The last set of systemic problems is related to the limited experimentation with incremental and disruptive technological innovations (SF1) and a missing supportive policy framework for upscaling these technologies in terms of market formation and necessary financial resources (SF5/SF6) (7 and 11, see Figure 12). As elaborated for SF1, there is a complex set of barriers due to difficulties to enter the market caused by a dominating duopoly of aircraft OEMs (12), safety and certification regulations (13) that are costly and time-consuming due to long lead times and also due to the financial resources necessary to invest in this high-tech sector.

Firstly, the duopoly of two large aircraft OEMs that is dominating the market (SF1) (12) is so strong that it is active in the mission arena (as a participant at the SAT), the overall MIS as industry actor, and in the international context. This duopoly determines the landscape of the international context in which is decided which innovations are worth to developing to higher TRLs or not. At this moment, there is no incentive due to large investments in production facilities and aircraft orders worth billions in the upcoming years (Airbus, 2021). A strong European regulatory framework to incentivize these aircraft OEM to focus on sustainable innovations is missing (9). This is caused by a lower priority for sustainability by some other nations (10), as elaborated in Section 4.4.2.

Secondly, another identified barrier are the strict safety regulations for certification (SF4a) (13). These certifications take a long time to complete and bear high costs (14). The resulting long lead times and costs involved to participate in this high-tech sector result in insufficient financial resources in the sector to experiment and upscale innovations (11). While the sector is willing to invest in innovation, more support is necessary to realize innovations.

Thirdly, as indicated for SAFs there is at this moment a missing long-term focus with assurances (6) concerning a supportive policy framework in the Netherlands. As OM2 indicates: "a technology push from below gives more steering. The government has the buttons to do so, otherwise, businesses leave the country, and we have to import technology from abroad". Therefore, a focus on technological innovations, which are possible to realize in the Netherlands is missing. For instance, by aiming to be part of the supply chain of the large aircraft OEMs more innovations can be supported for upscaling. There might also be a need to rethink the air transport system as it is right now. By, for instance removing ultra-long-haul flights which have a lot of emissions and are hard to abate, resources for innovations can be allocated on technological solutions that are feasible and bear reasonable abatement costs. Last, a lack of alternatives and a demand to have new innovative technological solutions reinforces the loop, as the commitment by actors will stay low unless the supportive policy framework is in place (1).

All three clusters of systemic barriers are processed into a complete overview (Figure 12). This overview shows how all barriers are interrelated with each other and what their position is in the mission arena, overall MIS, and international context. The numbers in this figure refer to the barriers explained in the text.

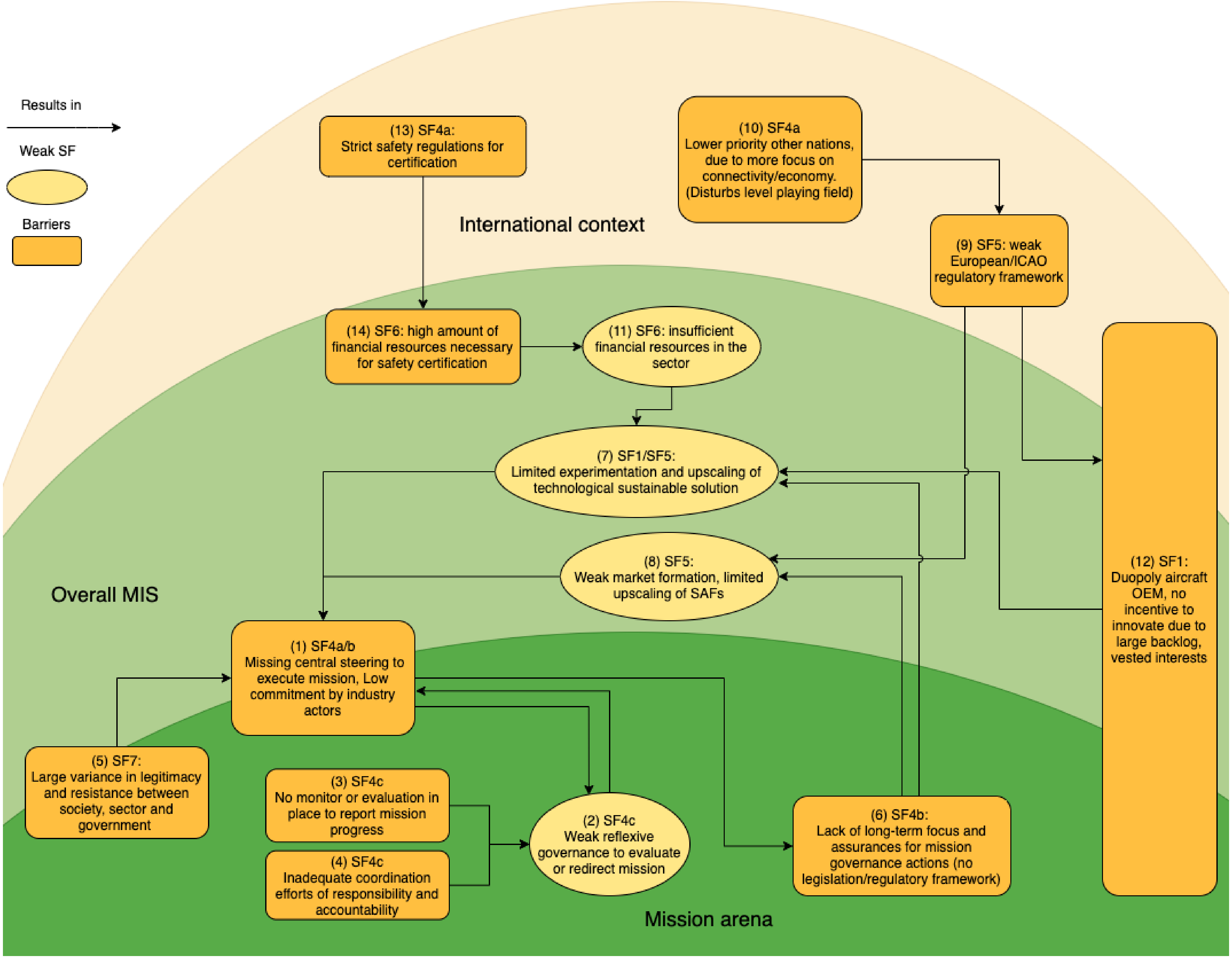

Figure 12, Complete overview interrelatedness barriers

4.5. Evaluation of governance actions

In this section, the systemic barriers and current mission policy targeting those barriers are discussed. There are many planned or recently implemented MGAs that target the identified systemic barriers (see **Error! Reference source not found.**, Section 4.2.3 and Appendix III). Many of these MGAs are currently work in progress and are being discussed and drafted by the government and participants at the SAT. It is therefore uncertain how the planned MGAs will look like in their final form when it becomes legislation.

For the planned MGAs targeting those barriers, a distinction is made between focus points and interventions. Focus points are important recommendations for actors and policymakers to pay attention to during the development to ensure that the barrier is addressed. These focus points are recommended by the researcher, based on interview data, expert consultations and literature. Interventions on the other hand, are policy recommendations for barriers which are not addressed because they are not in the scope of the governance action. For those (parts of) systemic barriers which are not targeted by either planned or recently implemented MGAs, interventions are proposed by the researcher. Interventions aim to add additional MGAs to the policy mix in order to eliminate or reduce the adverse effects caused by the systemic barriers. Table 7 shows a complete overview of the identified systemic barriers including planned or recently implemented MGAs, recommended focus points and interventions. The letters in the text refer to the focus points and interventions in Table 7.

4.5.1. Governance sustainable aviation

Firstly, interviewees indicated that the SAT needs to evolve from a negotiation table into an executive table in order to provide a central steering to execute the mission. The governance structure development plan is a planned MGA that is currently discussed at the SAT that targets this barrier. This plan discusses how the contents for the SAA can be translated into actionable points and aims to define the role of the table and its participants. It also aims to provide an answer about whether the table is only an advisory body or if it also has decision-making powers. When actionable points are defined, a steering can be established for a stronger governance to direct the mission as there is a clear vision of where to go. As a focus point (A), it is recommended to ensure that the actors at the SAT, in the mission arena and overall MIS are informed and are also involved in the selection and substantiation of long-term choices. Involving actors also increases their commitment and thereby potentially increases the legitimacy and reduces resistance. At this moment, there are no interventions necessary for this barrier, as policymakers and actors are aware of the barrier and are working on it.

Secondly, when a steering is established a long-term focus with assurances for industry actors that want to innovate is necessary. A long-term supportive framework to provide this can be realized via the innovation strategy. This planned MGA aims to make strategic choices for a strong eco-innovation system. The choices are based on the level of development (TRL) and the most important challenges encountered that hamper innovations and experiments to be developed and/or upscaled in the market. The outcome of the innovation strategy are actions for a long-term policy framework, investments and R&D activities for sustainable innovations. As a focus point (B), it is recommended to determine what type of stakeholders are participating in the mission arena and overall MIS and to understand how they relate to each other and what their contribution is to the mission. Similarly, a clear vision should provide assurances for a long-term supportive policy framework in order for participants to increase their commitment and willingness to participate in innovation. This thesis can serve as a starting point. As an intervention (C), it is recommended to ensure social innovations are also embedded in the innovation strategy. At this moment, there is a strong focus on technological innovations and less on social innovation. This also contributes to reducing the large variance in legitimacy and resistance between society, sector and government and thereby increases commitment by industry actors.

Thirdly, two barriers were identified resulting in weak reflexive governance. At this moment, there is no specific MGA planned to monitor or evaluate the mission, however there is one planned MGA, the CO_2-ceiling that could serve as a starting point to ensure the mission is on track by imposing a cap on emissions in the Netherlands. This MGA only slightly addresses the barrier and is therefore shown in italics. As this MGA is an ongoing discussion, it is unclear what the outcome is of a scenario where for instance actors are not willing to comply the set cap, which actor or institution is going to enforce this cap and what the consequences will be. This MGA on its own is therefore not sufficient to monitor, evaluate or redirect the mission. As a focus point (D) for this MGA, it needs to be ensured that actors comply with the set CO_2 cap in order to achieve to reduction targets. However, this MGA is also insufficient to monitor and evaluate the mission on its own. Therefore, as an intervention (E), it is recommended to establish a clear evaluation and redirection strategy of the mission progress after the steering and the long-term focus with a strong supportive policy framework with assurances are established. This entails establishing a governance structure that monitors, evaluates and redirects the mission. For instance, by focusing on the working groups and action programs, an additional structure in the system can be established that monitors whether the actions to achieve the mission is on track to achieve the set goals. An evaluation can be made to ensure what for instance the current TRLs and SRLs are of the innovation are and whether the perception of the problem and its solutions are aligned among actors. This strong monitoring and evaluation structure should also be able to redirect the mission if for instance the targets are becoming more stringent.

A second barrier hampering reflexive governance is about the inadequate coordination efforts of responsibility and accountability. The difference between the missing steering barrier is that this barrier is about the coordination among actors in terms of who is fulfilling what role and who is in the lead. The governance structure development plan for the SAT is also the MGA that is able to provide answers to those questions. As a focus point (F), the proposed public-private cooperation in the specific working groups and action programs could serve as a starting point to clearly divide roles among the government and the industry actors to divide responsibilities and accountabilities. Also, for this barrier there are no interventions necessary, as policymakers and actors are aware of the barrier and are working on it.

4.5.2. Insufficient upscaling support for Sustainable Aviation Fuels (SAFs)

To establish more upscaling support for SAFs, a supportive regulatory framework on both national and EU level is necessary to ensure that there is a market for the production and uptake of these fuels. Therefore, these two barriers are combined as the MGAs are targeting both barriers. First, there are two MGAs about a blending obligation for SAF, one on national and one on European level. The national blending obligation is an ongoing discussion between the Dutch government, fuel producers and the users of the fuel (airlines). Currently 14% is proposed as the amount for this blending obligation in 2030. Airlines indicate that there is a price difference between kerosene and SAFs. While this difference would eventually be paid by the user of the airline, for instance consumers, there needs to be a level playing field at least across Europe, and preferably even global. Therefore, on European level there is a blending obligation of 5% in 2030. Another MGA is the proposed kerosene taxation of 33 cents/liter on European level (EC, 2021). This is an ongoing discussion but can further discourage the usage of fossil fuels.

As a focus point (G), there need to be assurances for both the producer and the user of the fuel. Therefore, sufficient facilities are necessary for both the production of the fuel and hydrogen as energy source. The production of synthetic aviation fuel, which is the most sustainable fuel, requires a massive amount of hydrogen, which is why this resource is specifically mentioned (Van der Sman et al., 2021). The fuel and/or required resources could also be imported from other countries, as long as it can be used by the airlines in order to comply with the set targets of the blending obligation. Other types of fuels should also be supported in order to comply with the targets. Another focus point (H) is about the need to establish a level playing field for all airlines when imposing these obligations and taxations. As intervention (I), it is proposed to ensure that the price difference is compensated in order for airlines to use the most sustainable SAF, which is synthetic fuels and is currently three times more expensive compared to biofuels (Van der Sman et al., 2021). A temporary financial support for upscaling can be used until the production is up to speed and unit cost fall.

4.5.3. Missing policy framework for incremental and disruptive technological innovations

For technological innovations, there is an innovation strategy being drafted that will focus on those innovations that are deemed feasible to contribute to the mission. This strategy can be an excellent tool to realize a long-term vision to select what innovations to focus on. The innovation strategy (see Section 4.5.1) is a planned MGA which can provide a policy framework for the upscaling of experiments for incremental and disruptive technological innovations. When the innovation strategy has provided which stakeholders are involved to solve the barrier about a missing central steering for the mission it can further define the value chains and targets for the innovation scope to solve this barrier. As a focus point (J), it needs to be ensured that a strong regulatory framework provides more focus on which technological experiments to focus on and what markets to upscale. Furthermore, another focus point (K) is about what contributions to new disruptive technologies are worth the long-term investment. For a strong solution directionality, it is important to understand what solutions are most feasible to invest in. For instance, shorter flights instead of focusing on technology development or using large quantities of sustainable fuels for ultra-long-haul flights. As an intervention (L), there should be more social innovations embedded into the innovation strategy. Currently, there is a strong focus on technological innovation and less on social innovation. Another intervention (Q) is also related to (J) and (K) as there should be funding available for qualifying experiment that are feasible in the long-term. There are financial instruments, such as grants and loans available, that can be used for this.

Secondly, for safety certification it is very important to comply with the strict safety regulations imposed by the European Union Aviation Safety Agency (EASA). No compromises can be made to the strictness, however, more room to support testing and experimentation could accelerate the certification process and as a result cost reduction. This planned MGA aims to provide more room and possibilities to experiment and it also focuses more on the more specific financial requirements for the long lead times of certification processes. As a focus point (M), a more tailored approach for aviation is necessary. Current financial instruments are often too generic and not suitable for long lead times and are often too low as well according to a policymaker (PM4). Aviation is sometimes excluded from financial instruments such as grants and loans, as the instruments are often only valid for national industries and aviation is considered an international sector according to a policymaker (PM4). As an intervention (N), there needs to be a focus on the possibilities to speed up the progress and making the certification process costs lower through providing financial support (for instance loans). Entrepreneurs will have an increased incentive to invest in sustainable solutions. At this moment, there are financial instruments such as R&D budgets (TSH and RDM) and the finance strategy and growth fund can serve as a tool to further indicate what the requirements are for the qualification of funding and grants. Taxes, such as a kerosine levy could further destabilize the attractiveness of fossil fuels and incentivize the innovation of sustainable alternatives.

Thirdly, the MGAs for the duopoly barrier and weak European/ICAO regulatory framework are combined since these are closely related to each other. A stronger regulatory framework could incentivize the large aircraft OEM to invest in sustainable alternatives. These barriers are targeted by two MGAs. First, the Memorandum of Understanding (MoU) between the Netherlands Aerospace Group (NAG) and Airbus is an MGA initiated by the industry. The purpose of the MoU is to create a long-term strategic relationship in the field of sustainable aviation research and innovation, for both academic and industrial parties (NAG, 2021). The other MGA is the Clean Sky research project, which is a research program with R&D funding for SMEs, industry members, universities and research facilities contributing to innovation in the aviation sector (Clean Sky, 2021). A focus point (O) is to focus on how the Dutch innovation system can contribute to the supply chain of large aircraft OEMs. If the SAT and government would foster initiatives such as the MoU, the innovation system will become more successful as there is more cooperation among private actors. There is a need to support and incentivize start-ups, SMEs, industry, knowledge institutes, universities, and so on, to experiment with aircraft components such as new types of wings, hydrogen propulsion, electric flying or retrofitting. These small innovators can find their way from General Aviation to large commercial aviation. As an intervention (P), through regulations and a supportive framework on EU level, aircraft OEMs and engine manufacturers could also be incentivized to put effort into the development of technological innovations. Examples are for instance the CO_2 standards should become more stringent or other regulations to ensure emissions are reduced by encouraging the integration of fuel-efficient technologies into aircraft design and development (ATAG, 2016).

Table 7, Systemic barriers and planned or recently implemented MGAs

Systemic barriers (and interrelated system functions)	Planned or recently implemented Mission Governance Action(s) (MGAs) (see Appendix III)	Focus points	Interventions
Governance sustainable aviation			
Missing central steering to execute mission, Low commitment by industry actors (SF4a/b)	Governance structure development plan for the SAT is about defining the role of the table and its participants. The governance structure needs to be clearer whether the SAT is an advisory body or whether it also has decision-making powers? Who is fulfilling what role and who is in the lead? This MGA aims to answer those questions.	(A) It needs to be ensured that the actors at the table, in the mission arena and overall MIS are informed and are also involved in the selection and substantiation for long-term choices. Involvement increases commitment and thereby increases legitimacy and reduces resistance (SF7).	-
Lack of long-term focus and assurances for (MGAs) as there is no legislation or regulatory framework yet (SF4b). Large variance in legitimacy and resistance between society, sector, and government (SF7)	The *Innovatiestrategie* (Innovation strategy) aims to make strategic choices for a strong eco-innovation system. The choices are based on the level of development of innovations and most important challenges encountered for sustainable aviation. The outcome are actions for a long-term supportive policy framework, investments and R&D for sustainable innovations.	(B) Determine the stakeholders, how do they relate to each other and what is their contribution. Provide a clear vision with assurances in the long-term supportive policy framework for participants to increase their commitment.	(C) Ensure that social innovations are also embedded into the innovation strategy. Currently there is a strong focus on technological innovation and less on social innovation, which also contributes to the large variance in legitimacy and resistance between society, sector and government (SF7).

Weak reflexive governance to evaluate or redirect the mission (SF4c), caused by:			
• No monitoring or evaluation in place to report mission progress.	- *CO_2-ceiling: planned instrument in development. A national cap on emissions in the Netherlands for the aviation sector. Ongoing discussion with no clear answer about enforcement and compliance yet.*	(D) Ensure that all actors comply with the set CO_2 cap in order to achieve to reduction targets. However, this MGA is insufficient to monitor and evaluate the mission itself.	(E) Additional monitoring or evaluation structure/system to monitor, evaluate and/or redirect the mission. A clear evaluation and redirection strategy of the mission progress through the use of a governance structure focusing on the working groups and action programs. • Evaluate the current TRLs and SRLs of innovations. • Assess the perception of the problems and solutions relevant to the mission. • Strong monitoring and evaluation structure to redirect the mission if for instance the reduction targets are becoming more stringent.
• Inadequate coordination efforts of responsibility and accountability.	Governance structure development plan for the SAT. Coordination efforts is closely related to the missing steering, but defines who is fulfilling what role, who is in the lead and what the responsibilities and accountabilities are.	(F) Proposed public-private cooperation in the specific working groups and action programs could serve as a starting point to clearly divide roles among the government and the industry actors to divide responsibilities and accountabilities.	-

Insufficient upscaling support for Sustainable Aviation Fuels (SAFs)			
Weak market formation (SF5), limited upscaling of SAFs due to lack of alternatives Weak European/ICAO regulatory framework (SF5)	Blending obligation 14% for SAF target in 2030. Aircraft are obliged to tank this amount of sustainable fuel. (Rijksoverheid, 2020a) European blending obligation 5% for SAF target in 2030. (Part of the ReFuelEU and Renewable Energy Directive (RED) II legislation on EU level) (EC, 2021) A Kerosine taxation of 33 cents/liter is proposed on European level to discourage the usage of fossil kerosine.	(G) Assurances for producer and user. Ensure upscaling support production facilities/hydrogen production facilities or import fuel in order to comply with the set targets. (H) Ensure to establish a level playing field for all airlines when imposing these obligations and taxations.	(I) (Temporary) supportive financial instruments to reduce price difference between specific SAFs. This is temporary support for upscaling until production is up to speed and unit cost fall. Focus on the usage of SAFs that are more sustainable. For instance, synthetic SAF is 3 times more expensive compared to biofuels, while synthetic SAF is more sustainable.
Missing policy framework for technological innovations			
Limited experimentation and upscaling of technological sustainable solutions (SF1/SF5)	*Innovatiestrategie* (Innovation strategy) aims to make strategic choices for a strong eco-innovation system. The choices are based on the level of development of innovations and most important challenges encountered for sustainable aviation. The outcome are actions for a long-term supportive policy framework, investments and R&D for sustainable innovations.	(J) Make sure that a strong regulatory framework provides more focus on which technological experiments to focus on and what markets to upscale. (K) Focus on innovations that are feasible in the long-term, for instance technology for shorter flights instead of (ultra)long-haul flights	(L) More social innovations need to be embedded into the innovation strategy. Currently there is a strong focus on technological innovation and less on social innovation.

Strict safety regulations for certification (SF4a)	*Test- en experimenteerruimte* (Room for testing and experimentation) is a very recently planned governance action in development. Its divided into manned and unmanned aviation. Its goal is to enlarge room and possibilities for experiments while also focusing more specific on the financial requirements for the lead time of the certification processes.	(M) Safety requirements are very high for aviation. A more tailored approach for aviation is necessary. The financial instruments are often too generic and not suitable for long lead times and often too low as well. Aviation is sometimes excluded as it is deemed international and only national grants or loans are provided.	(N) The certifications rules are imposed by EASA. No compromises can be made to the strictness. However, by looking at possibilities to speed up the progress (accelerate) and making the certification process costs lower through financial support (for instance loans), entrepreneurs will have an incentive to invest in sustainable solutions.
Duopoly aircraft OEM, no incentive to innovate due to large backlog, vested interests (SF1) Weak European/ICAO regulatory framework (SF5)	The Memorandum of Understanding (MoU) between the Netherlands Aerospace Group (NAG) and Airbus is an MGA initiated by the industry. The purpose of the MoU is to create a long-term strategic relationship in the field of sustainable aviation research and innovation, for both academic and industrial parties (NAG, 2021). Clean Sky is a research program contributing to innovation in the aviation sector with R&D funding for SMEs, industry members, universities and research facilities. Part of the Horizon 2020/Horizon EU research funding program of the European Union (Clean Sky, 2021)	(O) Be in the supply chain of large aircraft OEMs. More cooperation among private actors. There is a need to support and incentivize start-ups, SMEs, industry, knowledge institutes, universities, and so on, to experiment with aircraft components such as new types of wings, hydrogen propulsion, electric flying or retrofitting for instance.	(P) Regulations and supportive policy on EU level to incentivize aircraft OEMs and engine manufacturers. For instance, CO_2 standards to reduce emissions need to become more stringent (ATAG, 2016).

Insufficient financial resources in the sector (SF6)	Financial instruments that are available for the aviation industry and are planned or recently implemented: • *Subsidieregeling* R&D *mobiliteitssectoren* (RDM) (Subsidy scheme mobility sectors) • TopSector High Tech (TSH) *vliegtuigmaakindustrie* (aviation industry) • *Groeifonds* (Growth fund) • *Financieringsstrategie* (Financing strategy) • *Investeringsfonds* (Investment fund)	-	(Q) Funding for qualifying experiments which are feasible in the long term. See (J) and (K).

5. Conclusion

For this research, a Mission-oriented Innovation System (MIS) analysis was conducted about the Dutch mission for sustainable aviation. In this section, an answer is provided to the research questions, and recommendations are given based on the evaluation of governance actions. The main research question of this thesis was: "Do the ongoing or planned Mission Governance Actions (MGAs) in support of the Dutch MIS to reduce CO_2 in international aviation adequately target the barriers of that MIS?". To answer this question the five steps of the structural-functional approach of the MIS were followed. The ten sub-questions based on these five steps have also all been answered in this thesis. 32 interviews, an extensive literature review, and numerous expert consultations provided data for these different steps. Many systemic barriers were identified from the system function analysis and many planned or recently implemented Mission Governance Actions (MGAs) were identified. This resulted in three networks of the most pressing interrelated systemic problems: one about the governance, and a missing central steering of the mission, another about insufficient upscaling support for Sustainable Aviation Fuels (SAFs), and a third network of barriers about a missing policy framework technological innovation.

Firstly, there is a missing central steering of the mission. The Sustainable Aviation Table (SAT) is the body that needs to evolve from a negotiation table into a more executive and coordination to coordinating table to steer the mission. To translate the contents of the Sustainable Aviation Agreement (SAA) into actionable points, strong governance with a focus on a central execution of the mission is necessary. The governance structure development plan for the SAT is about defining the role of the table and its participants. The governance structure needs to be more clear about whether the SAT is an advisory body or whether it also has decision-making powers. Also, who is fulfilling what role and who is in the lead? This MGA is an ongoing discussion that aims to answer those questions.

Secondly, the insufficient upscaling support for SAFs is addressed by the national and European blending obligations of respectively 14% and 5% in 2030 (Rijksoverheid, 2020a; EC, 2021). To ensure assurances for the producer and user of the fuel there needs to be upscaling support for the production facilities, or fuel needs to be imported from other countries to comply with the set targets. At the same time, a level playing field needs to be assured on the European level when imposing these obligations. To foster the usage of SAFs, a (temporary) financial instrument could reduce the price differences between for instance synthetic SAF and biofuels until production is up to speed and unit cost fall.

Thirdly, a missing policy framework for technological innovations resulted in limited experimentation and upscaling of technologies. The *Innovatiestrategie* (Innovation strategy) is a tool that can provide actions for a long-term supportive policy framework, investments, and R&D for sustainable innovations. At the same time, there should be a focus on long-term strategic relationships in the field of sustainable aviation research and innovation and there is a need to support and incentivize start-ups, SMEs, industry, knowledge institutes and universities to experiment with aircraft components by for instance focusing on being in the supply chain of large aircraft Original Equipment Manufacturers (OEMs). There should also be a focus on those technological innovations feasible in the long-term, for instance, technology for shorter flights instead of (ultra)long-haul flights that are hard to abate, and funding for those qualifying experiments, which are feasible in the long term.

This thesis also showed how powerful actors and institutions in an international context exert influence on other structural components. The case of sustainable aviation discussed in this thesis was useful to understand how large entities on European and international levels are affecting other MIS components. This affects governments to steer towards making effective national policies as they are bound to the international institutions that determine the behavior of actors.

To conclude, the Dutch mission for sustainable aviation has only recently started, but it has a lot of potential to address the identified barriers. There is a clear mission formulation, and the Sustainable Aviation Table is a mission governance body with a strong potential to steer and direct the development and diffusion of innovations. However, many of the MGAs are planned and still under development or are ongoing discussions. To answer the research question, the barriers will be adequately targeted if the elaborated focus points are followed.

5.1. Recommendations

This section discusses the recommendations for governance actors and policymakers. To address the identified systemic barriers, it is recommended to take the observed focus points into account when developing or discussing the corresponding MGA. The mission for sustainable aviation, as distinctively described in this thesis, is very complex and many barriers for different technologies have not been identified yet. Therefore, more research needs to be conducted to understand how the barriers are manifesting for different innovation systems. The Technological Innovation System (TIS) analysis could be used to approach to analyze specific parts of the innovation system, such as more disruptive technologies like hydrogen and electrical flying. Also, more research on European level is necessary to better understand how the barriers are hampering the development and diffusion on international level.

6. Discussion

6.1. Theoretical implications

Firstly, the thesis has empirically contributed by applying the concept of MIS in the case of international aviation. The MIS framework is a novel theory still under development. The empirical contribution of this thesis extends the body of literature by showing how MIS dynamics differ along different dimensions as each mission is unique (Wesseling & Meijerhof, 2021). Secondly, this thesis aimed to improve understanding of how an MIS relates to its geographical scope and ensuing coordination problems. Building on the work by Wesseling & Meijerhof (2021) the concept of the mission arena and overall MIS have been extended by adding a third element: the international context. As aviation is an international sector, the most effective policy can be achieved on European and global levels. This thesis has demonstrated that on an international level, there are dominant actors exerting influence on other structural components. This affects governments to steer towards making effective national policies as they are bound to the international institutions that determine how actors act. In a sector characterized by a lot of competition, low profit margins are making it difficult to allocate resources to innovation. So, an improved understanding of how these dominant actors and institutions affect the mission, guides analysts in their search for interactions. Likewise, it would also increase context-awareness amongst policymakers in which direction the mission is developing. More empirical research with different types of missions is necessary to understand how systemic barriers in the international context are affecting other structural components

6.2. Limitations

Firstly, one of the limitations for this research was the usage of the Likert scale. Literature states that weak fulfilled system functions need to be strengthened (Wesseling & Meijerhof, 2021). However, the analysis showed that interrelated barriers find their root cause often in another function than the one identified as scoring weakest. Therefore, more focus on the interrelated barriers is needed instead of the scoring of the system function. For example, in the analysis SF4c (reflexivity) was scored lower compared to SF4a (problem directionality) and SF4b (solution directionality). When the focus is on the weakest fulfilled function, efforts would aim to improve SF4c (reflexivity). However, if the barrier analysis showed that the root cause is found in SF4a or SF4b, then the focus should be first on those barriers. Subsequently, the barrier of SF4c can be removed in order to improve the structural components of the innovation system. Therefore, the Likert scale is rather a means to an end, and the literature should more explicitly emphasize on removing barriers instead of improving the weakly fulfilled system functions.

Secondly, for the *exnovation* of harmful activities of 'old' problematic practices and technologies a distinction in system function analysis was made (Wesseling & Meijerhof, 2021). The system functions[3] 2, 5, and 6 were split to allow the researcher to separately assess the innovation and *exnovation* activities in the system. As a result, different scoring between the innovation and exnovation parts of the system functions was identified. A large variance was found between de scoring of these exnovation activities, as different actor categories had a different vision about how to phase out. There was also ambiguity in the questioning, as some actors had difficulties to understand the difference between innovation and exnovation, while others did not see a difference at all. Therefore, the results appear to suggest that it is worthwhile to further develop this distinguishment and elaboration of splitting these functions into sub-functions. This provides a more specific insight which structural components are better performing on innovation and exnovation.

6.2.1. Limitations related to the aviation case

First, this MIS analysis of the Dutch sustainable aviation goals stated several policy recommendations to improve the innovation system. In the future, the goals might become more stringent to stay within a 1.5° to 2° Celsius global average temperature rise (IPCC, 2021). Many recent and upcoming assemblies at the European and UN-level might increase the set targets for aviation (ICAO, 2019). The Dutch government and aviation sector are aware of the possibility, meaning there is a limited reflexive governance. However, it is uncertain what the implications in terms of the number of aircraft movements are when technological and social solutions may be

[3] System functions: 2a (knowledge development), 2b (knowledge development focused on the out phasing of harmful activities), 5a (market formation), 5b (market destabilization), 6a (resource allocation), and 6b (resource reallocation)

inadequate to comply with more stringent reduction targets. When this would occur, additional or adjusted MGAs might be necessary to reduce the carbon footprint of the aviation sector. It is outside the scope of this research to determine the implications when this would occur. More research is necessary to prepare the government and aviation sector when this scenario may become reality.

Second, besides CO_2 emissions there is strong evidence of the adverse effects of non-CO_2 emissions, especially at cruise altitude levels in the atmosphere. A recent report, published by the European Union Aviation Safety Agency (EASA), shows that the radiative forcing of non-CO_2 emissions such as nitrogen oxides (NO_x), water vapor (H_2), and sulfate (SO_4) could do more harm (EASA, 2020). Further research is necessary to understand the impact on the innovation system and mission governance for sustainable aviation.

Third, interviewees stated that while the Netherlands has a relatively large aviation industry, it might not be the most ideal and efficient place for innovations to take place. Solutions for the identified problems to achieve sustainability might possibly come from other countries which are heavily involved in the aircraft manufacturing industry such as France and the USA. The rationale is that when solutions for the sustainable aviation are imported, the reduction targets can also be achieved. The Netherlands cannot achieve all efforts on technology and innovation on its own, therefore international cooperation is important. A selection needs to be made about what the Netherlands is going to invest in and what innovations are brought from outside the innovation system.

As a final remark, there might also be a need to rethink the air transport sector as it is right now. Actors need to realize that the future is going to be different and that we need to adapt. More self reflection and awareness about the changing environment would mean to rethink what we want as a society and that careful choices might be necessary in order to achieve the reduction goals.

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Appendix I – Case description and participating actors

The aviation sector is one of the hardest sectors to decarbonize. Aircraft have to lift their fuel and carry it with them. This requires energy-dense fuels capable of providing high power outputs. Battery powered cars have the potential to revolutionize road transport but are unlikely to serve as a power source for long-haul commercial flights in the next couple of decades. Hydrogen has a much higher potential, but requires a completely new generation of aircraft, engines and fuel infrastructure which takes about 20-30 years to realize.

In 2009, the International Civil Aviation Organization (ICAO) presented the commitments by the aviation sector to reduce worldwide emissions. These include a 2% annual fuel efficiency increase of aircraft, stabilization of emissions, a carbon neutral growth from 2020 and a 50% CO_2 reduction in 2050 compared to 2005 (Rijksoverheid, 2020a). ICAO is also working on a long-term aspirational goal (LTAG) with more far-reaching measures for international aviation to reduce its emissions. The LTAG is expected to be presented in 2022 (ICAO, 2019). In addition, the global aviation industry has committed itself to cut net carbon emissions to half of what they were in 2005 by 2050 (ATAG, 2020). Moreover, the European Commission has set out transport emission reductions via the European Green deal. The aviation sector has to contribute to a net reduction of 90% by 2050 (compared to 1990-levels) for transport emissions (EEA et al., 2019).

In May 2020, the Dutch Ministry of Infrastructure and Water Management (I&WM) presented the draft Civil Aviation Policy Memorandum 2020-2050 (Rijksoverheid, 2020a). This memorandum provides a framework for the developing of the aviation sector in the Netherlands for the upcoming decades. Four public interests: safety, connectivity, quality of life and sustainability are included in this memorandum. International reduction targets for flights departing from the Netherlands are based on how much fuel is uplifted at Dutch airports (Rijksoverheid, 2020a). The reduction targets for international CO_2 emissions, which is the mission discussed within the scope of this thesis, are: in 2030 minimally down to 2005 levels, in 2050 a 50% gross reduction compared to 2005 levels, and for 2070 zero emissions in the sector (Rijksoverheid, 2020a). The Dutch Climate Agreement has as target to reduce domestic emissions with 95% in 2050 compared to 1990 levels. The aim for ground operations at airports, such as baggage transport is to have zero emissions in 2050.

There are 34 actors (see table below) participating in the Sustainable Aviation Table (SAT). Together with the Ministry I&WM and the Ministry of Economic Affairs and Climate Policy (EZK), these parties are involved in the negotiation and decision-making. The SAT is a platform where actors are meeting each other and agree on what actions to take to achieve the set goals in the policy memorandum. This thesis aims to understand whether current Mission Governance Actions (MGAs) are adequately addressing the barriers in the Mission Innovation System (MIS) of the Dutch mission for sustainable aviation.

Actor (34)	Type
Airbus	Aircraft OEM
Boeing	Aircraft OEM
Embraer	Aircraft OEM
GKN Fokker	Aircraft OEM
Corendon	Airline
Easyjet	Airline
Koninklijke Nederlandse Luchtvaartmaatschappij (KLM)	Airline
Transavia	Airline
TUI	Airline
Groningen Airport Eelde	Airport
Royal Schiphol Group	Airport
Eindhoven Airport	Airport
Mulder Aviation Consulting	Consultantcy
PwC	Consultantcy
Evofenedex	Employees association
KNVvL	Employees association
VNO-NCW	Employees association
Neste	Energy sector

Port of Rotterdam	Energy sector
Shell	Energy sector
SkyNRG	Energy sector
Ministry of Defense	Government
Ministry of Economic Affairs and Climate Policy (EZK)	Government
Ministry of Infrastructure and Water Management (I&WM)	Government
DNATA	Ground handler
Air Cargo Netherlands (ACN)	Industry Association
AOPA	Industry Association
BARIN	Industry Association
LRN	Industry Association
NACA	Industry Association
Luchtverkeersleiding Nederland (LVNL)	Infrastructure
NLR	Knowledge institute/university
TU Delft	Knowledge institute/university
ANVR	Travel agency

Appendix II – Technological and social solutions

Solution	Description	TRL/SRL[4] (Technology/social readiness level)	(Dis)advantages (Peeters & Melkert, 2021; Van der Sman et al., 2021)
Renewable fuels • Sustainable Aviation Fuels (SAFs) ○ Biofuels ○ Waste fuels ○ Synthetic e-fuels	These fuels have lower CO_2 emissions compared to conventional Jet A1 kerosene aviation fuel. Compatible with current generation aircraft engines, therefore known as 'drop-in' fuels.	TRL 6-7	+ Synthetic e-fuels can be upscaled in large quantities using hydrogen - There are still CO_2 emissions at high altitudes - Waste fuels require a lot of waste as a resource for high volumes - Biofuels affect land usage and biodiversity
• Hydrogen	Hydrogen can be used as an energy source for the production of SAF. Or as fuel for alternative propulsion, liquid or gaseous.	TRL 4-5	
More efficient aircraft improvements • Less drag (more aerodynamical) • More fuel-efficient engines	Incremental efficiency improvements with current aircraft designs.	TRL 6-9	+ Aircraft are on average 1-1,5% more fuel efficient each year due to improvements of next-generation aircraft (15-20% in total). - However, due to a 4-5% yearly growth this solution is insufficient to reduce emissions on its own.
New aircraft designs	New designs such as blended wings.	TRL 2-4	+ More fuel-efficient design, less drag. - Many technological challenges, therefore, not available for commercial application in the short-term.
Alternative propulsion • Electric	Electric engines using batteries or a fuel cell. Batteries are very heavy. A fuel cell with hydrogen is the most energy efficient solution (Peeters & Melkert, 2021).	TRL 2-6	+ 2-3 times more fuel efficient compared to turbine engine. + Fuel cells are light, less weight compared to batteries.

[4] These SRL are only defined for the Netherlands. In other countries (outside EU) these SRLs could be significantly lower.

			- Batteries are very heavy, 7-15 times higher capacity per kg batteries required than available today. Not available in short-term.
• Hydrogen	Hydrogen directly in turbine engine with some modifications (Kivits, Charles, & Ryan, 2010)	TRL 2-6	+ Also very efficient, less heavy compared to battery - More volume required, cooled or high-pressure systems. Inflammable and explosive and therefore hard to comply to safety regulations. - Higher well-to-wing energy necessary compared to hydrogen fuel cell.
• Hybrid	Hybrid can be a combination of: Battery + fossil fuel Fuel cell + fossil fuel Fuel cell + hydrogen turbine	TRL 2-6	+ There are technological challenges when using a fuel cell only. A safety issue is it takes time before full power is available. During a go-around a additional hybrid solution such as an extra battery to give the fuel cells extra charge or fossil fuel or direct hydrogen burn. - Hybrid solutions are heavier, meaning less passengers can be aboard.
Optimization of Air Traffic Management (ATM) and aircraft operations • ATM improvements • 'Smart' and efficient processes during aircraft operations.	For instance, shorter flight routes with optimized ATM. More 'smart' and efficient ways of operating the aircraft at the airport and during the flight by personnel.	TRL 7-9 / SRL 6-8	+ Theoretically it seems easy to implement and realize. -3 Interviewees indicate that these are small reductions in combination with a very political contested context (about sovereignty, borders and laws) requiring relatively lots of effort and financial resources.
Alternative transportation modes • Electric rail • Bus	Substitute flights by train or bus. Nudging citizens to use alternative transportation.	SRL 6-8	+ Significant lower carbon footprint emissions compared to flying (CE Delft, 2019) - Price, comfort and travel time only on

			a few destinations comparable to flying at this moment - Total carbon reductions on short-haul flights have limited benefits because the majority of emissions is on long-haul flights and if seats are replaced by other passengers there is no benefit in CO_2 reduction. - Higher internalized costs compared to flying due to high infrastructural costs, (CE Delft, 2019)
Awareness and consumer behavior		SRL 6-8	
• Communication about the impact of flying	Creation of public awareness about the negative effects of flying to the environment. For instance eco-labels.		+ Selection of 'clean' airline compared to more polluting ones. - Limited effective to reduce CO_2 as it is up to individual choice.
• Reduce or refuse flying	Examples: 1. Adapt to achieve purpose of travel goals at shorter distance. 2. Less holidays per year 3. Working from home 4. Stop flying altogether	SRL 4-6	+ Strong reduction of CO_2 footprint. - If other passengers would take the free seat, there is no reduction. - Requires strong cultural change/ new social norm
• CO_2 compensation	Planting trees, invest in sustainable projects.	SRL 6-8	+ Some reduction in other sectors - Hard to manage/monitor the effects, chance of 'greenwashing'.

Appendix III – Mission Governance Actions (MGAs)

Mission Governance Actions (MGAs) related to identified systemic barriers	Description
Dutch MGAs	
Blending obligation Sustainable Aviation Fuels (SAFs) 14% in the Netherlands in 2030	The Dutch target is a 14% blending obligation of SAF in 2030. The blending obligation was initially proposed by the industry itself. Airlines are obliged to tank at least 14% of their fuels in the Netherlands sustainable. The outcome of this governance action is still unclear as it is an ongoing discussion. There is a debate about how the production is going to be realized, who is going to pay for the price difference compared to kerosene and what to do about tankering (fueling in other countries) to ensure a level playing field is kept. *See also the European blending obligation of 5% below.*
Innovatiestrategie (Innovation strategy)	The innovation strategy aims to make strategic choices for a strong eco-innovation system. The choices are based on the level of development of innovations and most important challenges encountered for sustainable aviation. The outcome are actions for long-term investments and R&D for sustainable innovations.
Test- en experimenteerruimte (Room for testing and experimentation)	Certification is very important to comply with the strict safety regulations imposed by the supranational organization European Union Aviation Safety Agency (EASA). A distinction is made between manned and unmanned aviation. This planned governance action aims to create more room for testing and experiments while also focusing more specific on the financial requirements for the lead time of the certification processes.
Financial stimulation (Loans, grants etc.)	• *Financieringsstrategie* (Financing strategy) • *Groeifonds* (Growth fund) • *Investeringsfonds* (Investment fund) • *Subsidieregeling R&D mobiliteitssectoren* (RDM) (Subsidy scheme mobility sectors) • TopSector High Tech (TSH) *vliegtuigmaakindustrie* (aviation industry)
Ticket taxes	Ticket tax to reduce price differences between other modalities and to make consumers more aware of the negative impact of flying. Effects in its current form are disputed.
Action Plan Air/Rail	I&WM together with KLM, Schiphol, NS and Prorail work together on this action plan focusing on six European city pairs as replacement for short-haul flights.

CO_2-plafond (CO_2-ceiling)	CO_2-ceiling: planned instrument in development. A national cap on emissions in the Netherlands for the aviation sector. Ongoing discussion with no clear answer about enforcement and compliance yet.
Memorandum of Understanding (MoU) between Netherlands Aerospace Group (NAG) and Airbus	The Memorandum of Understanding (MoU) between the Netherlands Aerospace Group (NAG) and Airbus is an industry-initiated MGA. The purpose of the MoU is to create a long-term strategic relationship in the field of sustainable aviation research and innovation, for both academic and industrial parties (NAG, 2021).
Kerosene taxation	The EU has recently announced a tax on kerosene of 33 cents/liter (EC, 2021). This is an ongoing debate to further discourage the use of fossil fuels and destabilize the market.
Governance structure development plan Sustainable Aviation Table	This plan discusses how the contents for the SAA can be translated into actionable points and aims to define the role of the table and its participants. It also aims to provide an answer about whether the table is only an advisory body or if it also has decision-making powers. When actionable points are defined, a steering can be established for a stronger governance to direct the mission as there is a clear vision of where to go.
European/international MGAs[5]	
Blending obligation Sustainable Aviation Fuels (SAFs) 5% in the EU in 2030	The EU target is a 5% blending obligation of SAF in 2030. The discussion here is more focused on how to ensure tankering and other unfair advantages air minimized for airlines entering from outside the EU. A level playing field is important to ensure. *See above the Dutch target for 14% in 2030 above.*
EU-ETS	The European Union Emissions Trading System is a market-based measure to trade CO_2 rights economy-wide with other sectors based on a price per ton of CO_2, which is increasing over the years with a cap.
CORSIA Monitoring, Reporting and Verification (MRV) System	Carbon Off-set and Reduction Scheme for International Aviation (CORSIA) is a system introduced globally to off-set emissions in aviation. The objective of CORSIA is to stabilize growth for international after 2020 through internationals credits (ICAO, 2021). The average baseline emissions between 2019 and 2020 determine the offset requirements for the sector in a specific year (ICAO, 2021).

[5] MGAs which are enforced by the mission arena and therefore relevant.

Clean Sky	Furthermore, the Clean Sky research program is contributing to innovation in the aviation sector with R&D funding for SMEs, industry members, universities and research facilities (Clean Sky, 2021).
Green Deal (*Fit-for-55*)	EU package with policy instruments to reduce 55% net CO_2 emissions in 2030 compared to 1990 levels. This includes the ReFuelEU initiative and Renewable Energy Directive II (RED). The EU has announced a 5% blending obligation for SAF 2030 and 20% for 2035.
SES(AR) – Single European Sky (Air Traffic Management Research)	EU research about the optimization of Air Traffic Management (ATM) Examples are a more unified network structure for European airspace and avoid the influence on flight routes, resulting from military matters, national borders, and predetermined air corridors (Heinrich Böll Foundation, 2016).

Appendix IV – Operationalization table

Structural functional analysis step MIS	Concept	Indicators from interviews	Indicators literature	Indicators resulting from analysis
Problem-solution diagnosis	Problems	Societal wants and needs in relation to sustainability	Societal wants and needs in relation to sustainability	
	Solutions	Technical and social solutions in development or used contributing to the mission	Types of solution (technical or social) Incremental or radical TRL and SRL Level	
Structural analysis	Actors	Government, companies in the sector, knowledge institutes, universities, NGOs and others.	Government, companies in the sector, knowledge institutes, universities, NGOs and others.	
	Institutions	Rules, regulations, laws, habits, norms, traditions, established practices etc.	Rules, regulations, laws, habits, norms, traditions, established practices etc.	
	Networks	Industry associations, interactions among actors, collaborations.	Industry associations, interactions among actors, collaborations.	
	Infrastructure/materiality	Physical infrastructure, knowledge (expertise, know-how) and financial (grants, subsidies)	Physical infrastructure, knowledge (expertise, know-how) and financial (grants, subsidies)	
	International Context interactions	Actors, institutions, networks and materialty on European and international levels.	Actors, institutions, networks and materialty on European and international levels.	
	Mission Governance Actions (MGAs)	Current and planned both government policy and actions initiated by the industry	Current and planned both government policy and actions initiated by the industry	

System function analysis	SF1	On a scale from 1 to 5: to what extent is entrepreneurship at this moment in your perception adequate to achieve the CO_2 reduction targets? - Why did you rate this function a <*number given*> and why not higher? - What is hampering this system function? - How can this barrier be overcome to improve this system function?		
	SF2a/b	(2a) On a scale from 1 to 5: how would you rate knowledge development to reduce CO2 for a more sustainable aviation? (2b) On a scale from 1 to 5: how would you rate the knowledge development concerning the phase out of unsustainable practices? - Why did you rate this function a <*number given*> and why not higher? - What is hampering this system function? - How can this barrier be overcome to improve this system function?		
	SF3	On a scale from 1 to 5: how would you currently rate the diffusion of knowledge among entrepreneurs, organizations, knowledge institutes, NGOs and governments? - Why did you rate this function a <*number*		

		given> and why not higher? - What is hampering this system function? - How can this barrier be overcome to improve this system function?		
	SF4a	(4a.1) How would you describe the functioning of the Sustainable Aviation Roundtable? (4a.2) On a scale from 1 to 5: to what extent is priority given to sustainable aviation (CO_2-reduction targets) in relation to other relevant societal challenges? - Why did you rate this function a <*number given*> and why not higher? - What is hampering this system function? - How can this barrier be overcome to improve this system function?		
	SF4b	(4b.1) On a scale from 1 to 5: how would you rate consensus among actors in the sector about what solutions have the priority to achieve the CO_2-reduction targets? - Why did you rate this function a <*number given*> and why not higher? - What is hampering this system function? - How can this barrier be overcome to		

		improve this system function?		
	SF4c	(4c.1) On a scale from 1 to 5: how strong is progress monitored and evaluated and, when needed, redesigned or redirected to achieve the CO_2-reduction targets? - Why did you rate this function a <*number given*> and why not higher? - What is hampering this system function? - How can this barrier be overcome to improve this system function?		
	SF5a/b	(5a) On a scale from 1 to 5: how strong would you rate the attractiveness of the market for developing and diffusing innovative solutions that contribute to CO_2-reduction? (5b) On a scale from 1 to 5: how strong would you rate the destabilization of existing CO_2 intensive markets? - Why did you rate this function a <*number given*> and why not higher? - What is hampering this system function? - How can this barrier be overcome to improve this system function?		

	SF6a/b	(6a) On a scale from 1 to 5: how would you rate the availability of resources from your organization/perspective that contribute to a reduction of CO_2 in aviation? (6b) On a scale from 1 to 5: are resources from your perception withdrawn from CO_2 intensive practices? - Why did you rate this function a <*number given*> and why not higher? - What is hampering this system function? - How can this barrier be overcome to improve this system function?		
	SF7	(7.1) On a scale from 1 to 5: to what extent is resistance counteracted and more legitimacy created for sustainable aviation in order to meet the CO_2-reduction targets? - Why did you rate this function a <*number given*> and why not higher? - What is hampering this system function? - How can this barrier be overcome to improve this system function? (7.2) What solutions receive the strongest lobby support or opposition?		

Systemic barriers analysis	Barriers most pressing problems hampering the development of the mission	(8) Are there additional barriers that inhibit innovation to make aviation more sustainable that have not been discussed before?		Weak system functions from the system function analysis linked to identified barriers
	Barriers most pressing problems hampering the development and diffusion of solutions			Weak system functions from the system function analysis linked to identified barriers
Systemic instruments analysis	Matching Mission Governance Actions (MGAs)			Analysis of current MGAs to adequately target identified problems
	Proposed or adjusted MGAs to target barriers			Alignment/adjustment of current or possible new MGAs to adequately target identified problems

Appendix V – Interview guide (English)

Interview Mission-oriented Innovation System (MIS) analysis sustainable aviation

Introduction

Your knowledge and expertise is valuable to contribute towards a more sustainable air transport system. Therefore, I would like to thank you for your time and efforts to participate. The duration of this interview is about an hour. The interview consists of nine theme's, the so-called innovation system functions. During the interview I kindly request you to rate each function on a scale from 1 to 5. I would also like to discuss the reason for your choice and what the problems are and what possible solutions could improve the fulfillment of each system function.

My name is Julian van Arkel, master's student Sustainable Business & Innovation at the Utrecht University, the Netherlands. I am conducting research for the Dutch Ministry of Infrastructure and Water Management (Directorate-General for Aviation and Maritime Affairs). For my research I am conducting a Mission-oriented Innovation System (MIS) analysis on how innovation in the aviation sector can be accelerated to achieve CO_2-emission targets in 2030 and 2050. The MIS is developed by the Copernicus Institute for Sustainable Development at the Utrecht University. The results of my research will be discussed with the organizations participating at the Dutch roundtable for sustainable aviation.

In an MIS analysis coordination among actors and possible solutions is essential. During the research it is assessed whether the (recently) implemented policy instruments address the identified barriers within the Dutch MIS. First, the structural analysis with all the actors involved in the mission is created. Together these actors determine the speed and direction of the innovation system. The MIS consists of the institutional structure (rules of the game), which strongly determine what these actors want, are able to do and what they are allowed to do. A well-functioning innovation system results in a rapid development and diffusion of innovation. In a system several reasons can result in barriers that inhibit innovation. Nine key innovation activities, the so-called system functions, analyze the barriers that inhibit the development and diffusion of innovation. In an MIS it is also important to consider the destabilization or phase-out of harmful activities in the current regime that use for instance fossil fuels.

The weak fulfilled system functions are analyzed for possible policy recommendations. The 'lock-in' is described as the constellation of habits, rules and regulations, actors and infrastructure that keeps the current system in place. In order to make aviation more sustainable this 'lock-in' needs to be broken up. By pressuring the regime novel innovations can gain more traction while at the same time support for initiatives that keep the current system in place are removed. The results of the research will be discussed and shared with the innovation working group in the context of the Dutch roundtable of sustainable aviation.

Informed consent

I would like to make an audio recording of the interview in order to analyze the data afterwards. Your answers will be processed confidential and completely anonymous in my thesis. Do you agree? If you change your mind during or after the interview, please let me know. You may of course always decide to refuse to answer a question.

Do you have any questions or remarks before we start?

Interview questions

The following questions are about the nine system functions. These are the key innovation activities. It is of importance for a transition towards sustainable aviation to research how the development and diffusion of innovation can be accelerated. At the same time through destabilization, harmful practices that need to be considered to be phased out are discussed. For each theme I would like to ask you to rate on a scale from 1 to 5 what the current fulfillment is of the theme (without the influence of the Covid-19 crisis).

Theme 1 - Entrepreneurial activities

Description 'entrepreneurial activities'	Both SME's (Small and medium-sized enterprises) and large companies. Experiments with (clusters of) solutions to enable learning; entering markets for new solutions; engaging in business model innovations to the diffusion of solutions.
Examples	• Experiments to learn. • Explore new technologies and startups. • Variations in the (existing) design. • New business models and market entry. • Investments of own resources in the development of technology. • Upscaling of technology and production capacity.
(1.1) On a scale from 1 to 5: to what extent is entrepreneurship at this moment in your perception adequate to achieve the CO_2 reduction targets? *1 weak entrepreneurship (few experiments), 5 strong entrepreneurship (many experiments)*	

Theme 2 - Knowledge development

Description 'Knowledge development'	Learning by searching and by 'doing', resulting in development and better understanding of new technical and social knowledge on problems and solutions, through R&D and scientific research.
Examples	• Research & Development activities. • Scientific research for technological and social solutions. • Knowledge development to phase-out activities that emit CO_2.
(2.1) On a scale from 1 to 5: how would you rate knowledge development to reduce CO_2 for a more sustainable aviation? (2.2) On a scale from 1 to 5: how would you rate the knowledge development concerning the phase out of unsustainable practices? *1 low knowledge development, 5 high knowledge development*	

Theme 3 - Knowledge diffusion

Description 'knowledge diffusion'	Sharing knowledge among actors in the aviation sector to develop solutions that contribute jointly to achieve the reduction targets. Stakeholder meetings, conferences, governance structures, public consultations, mission progress reports and other forms of disseminating technical and social knowledge for the mission's solutions and societal problems.

Examples	• Ways how technological and social knowledge is spread or shared about the problems and solutions concerning the achievement of the targets: • Stakeholder meetings, conferences, webinars, public consultation and mission progress reports.
(3.1) On a scale from 1 to 5: how would you currently rate the diffusion of knowledge among entrepreneurs, organizations, knowledge institutes, NGOs and governments? *1 low knowledge diffusion, 5 high knowledge diffusion*	

Theme 4 - Mission directionality

Theme 4a - Priority of sustainability (*Problem directionality*)

Description 'problem directionality'	The direction provided to stakeholders' societal problem conceptions and the level of priority they give it. Sustainability is one of many societal challenges for organizations to deal with in their day-to-day business. Not every topic can have the same level of priority. This could possibly have an impact to meet the CO_2 reduction targets.
Examples	• Priority sustainability on the agenda (CO_2-reduction) compared to other societal challenges such as safety, connectivity (economic) and quality of life (noise, air pollution). • Possible other topics that are of importance and need a high priority on the agenda compared to sustainability (CO_2-reduction).
(4a.1) On a scale from 1 to 5: to what extent is priority given to sustainable aviation (CO_2-reduction targets) in relation to other relevant societal challenges? *1 low priority sustainability, 5 high priority sustainability*	

Theme 4b - Priority of solutions (*Solution directionality*)

Description 'solution directionality'	The direction provided to the search for technological and social solutions, as well as the coordination efforts needed to identify, select and exploit synergetic sets of solutions to the mission. Strong solution directionality means there is consensus among actors which direction innovation needs to go. Unambiguous expectations about the future result in a reduction of risk perception among actors and increases their willingness to participate. Directionality can be generic: "the future of aviation will be sustainable" or very specific: "technology A will play an important role in making aviation sustainable". Spreading limited human and financial resources among many different trajectories will not lead to an acceleration of the transition. A loss of direction in which solutions are not fully developed in order to change the regime results in weak solution directionality.
Examples	• Priority of solutions that contribute to CO_2-reduction. • Being aware of the interdependencies between solutions and also using them (For example: technology X influences technology Y). • Support for solutions that contribute to the phasing out of harmful practices emitting CO_2.

(4b.1) On a scale from 1 to 5: how would you rate consensus among actors in the sector about what solutions have the priority to achieve the CO_2-reduction targets? *1 weak solution directionality, 5 strong solution directionality*

Theme 4c - Reflexive governance

Description 'reflexivity'	Reflexive monitoring, anticipation, evaluation and impact assessment procedures, which provides the analytical and forward-looking basis for redirecting the system's problem framing and search for solutions based on lessons learned and changing context. It can be seen as second order directionality.
Examples	• Monitoring, evaluation, anticipation, evaluation, reporting and impact assessment procedures. • Independent (e.g., dedicated task force) and transparent. • Reorienting the mission when necessary to achieve the targets.
(4c.1) On a scale from 1 to 5: how strong is progress monitored and evaluated and, when needed, redesigned or redirected to achieve the CO_2-reduction targets? *1 weak reflexivity, 5 strong reflexivity*	

Theme 5 - Market formation and destabilization

Description 'market formation and destabilization'	Creating niche markets and upscaling support for technical and social solutions; phasing out or destabilizing markets for practices and technologies harmful to the mission.
Examples	• Demand from the sector for innovative solutions. • Support for creating niche markets. • Support for upscaling. • Destabilization (policy/tax) • Phasing-out of harmful activities (CO_2 intensive).
(5.a) On a scale from 1 to 5: how strong would you rate the attractiveness of the market for developing and diffusing innovative solutions that contribute to CO_2-reduction? *1 low market formation, 5 high market formation* (5.b) On a scale from 1 to 5: how strong would you rate the destabilization of existing CO_2 intensive markets? *1 weak destabilization, 5 strong destabilization*	

Theme 6 - Resources (re)allocation

Description 'Resources (re)allocation'	Mobilization of human, financial and material resources to enable all other system functions.
Examples	• Financial resources • Human resources (educated people)

	• Materials (raw materials, fuels) • Reallocation of resources from harmful CO_2 intensive practices.
(6.1) On a scale from 1 to 5: how would you rate the availability of resources from your organization/perspective that contribute to a reduction of CO_2 in aviation? *1 low availability resources, 5 many available resources* (6.2) On a scale from 1 to 5: are resources from your perception withdrawn from CO_2 intensive practices? *1 low withdrawal of resources, 5 high withdrawal of resources*	

Theme 7 – Counteracting resistance to change

Description 'counteracting resistance to change'	Creating legitimacy for prioritizing a) the problem and b) the development and diffusion of its solutions. To counteract resistance to change for a more sustainable aviation, the current regime needs to adapt. The current system consists of a constellation of habits, rules and regulations, actors and infrastructure that reinforces itself. In this situation there is low uptake of mostly costly and (at first) inferior technologies. In the innovation literature this is called 'lock-in'. To accelerate the development and diffusion of innovation it is of importance to increase the priority of sustainable aviation including its solutions. This results in more legitimacy, while at the same time the 'lock-in' can be broken open by withdrawing legitimacy from harmful carbon intensive practices.
Examples	• Resistance to the growth of aviation. • Sustainability higher on the agenda. • Advocating or lobbying for sustainable technologies. • Creating public support.
(7.1) On a scale from 1 to 5: to what extent is resistance counteracted and more legitimacy created for sustainable aviation in order to meet the CO_2-reduction targets? *1 low legitimacy/high resistance, 5 high legitimacy/low resistance* (7.2) What solutions receive the strongest lobby support or opposition?	

Additional systemic problems

(8) Are there additional barriers that inhibit innovation to make aviation more sustainable that have not been discussed before?

Appendix VI – Interview guide (Dutch)

Vragenlijst Missie-gedreven Innovatiesysteem (MIS) analyse Duurzame luchtvaart

Introductie

Uw kennis en expertise is waardevol om de transitie naar een duurzamere luchtvaart te kunnen realiseren. Daarom wil ik u bedanken dat u bereid bent uw tijd en moeite te investeren in dit interview. De duur van het interview is ongeveer een uur. Het interview bestaat uit negen thema's, de zogenaamde systeemfuncties van het innovatiesysteem. Tijdens het interview vraag ik u om iedere functie een score van 1 tot 5 te geven en om uw keuze toe te lichten.

Achtergrond onderzoek

Mijn naam is Julian van Arkel, masterstudent Sustainable Business & Innovation aan de Universiteit Utrecht. Ik ben bezig met een onderzoek voor het Ministerie van Infrastructuur en Waterstaat (directie luchtvaart) onder begeleiding van Robbert Thijssen (directiebrede coördinatie kennis en innovatie) en Pieter Groskamp (Omgevingsadviseur duurzame luchtvaarttafel). Voor mijn onderzoek voer ik een Missie-gedreven Innovatie Systeem (MIS) analyse uit om te onderzoeken hoe innovatie in de luchtvaartsector kan worden versneld om de CO_2-reductiedoelstellingen te kunnen behalen. De MIS is ontwikkeld door het Copernicus Institute of Sustainable Development aan de Universiteit Utrecht op basis van het Technologisch Innovatie Systeem (TIS) model. Bij een MIS is het op voorhand niet duidelijk welke oplossingen de beste kansen bieden om een maatschappelijke uitdaging te lijf te gaan. Coördinatie tussen partijen en oplossingsrichtingen is daarom essentieel.

Tijdens het onderzoek wordt er gekeken of de beleidsinstrumenten die zijn óf worden geïmplementeerd om de Nederlandse missie voor CO_2-reductie in de luchtvaart te kunnen behalen aansluiten op de geïdentificeerde knelpunten in de MIS. Als startpunt voor het MIS raamwerk worden de actoren in kaart gebracht die onderdeel zijn van de missie. Gezamenlijk sturen zij de snelheid en richting van het innovatiesysteem. De MIS bestaat uit de institutionele structuur (regels van het spel), die sterk bepalend is voor wat deze actoren willen, kunnen en mogen. Als het innovatiesysteem goed functioneert leidt dit tot snelle ontwikkeling en verspreiding van innovaties. In een systeem kunnen verschillende redenen zijn waarom het systeem niet goed functioneert. Aan de hand van negen sleutelfactoren, de zogenaamde systeemfuncties van het innovatiesysteem, wordt gekeken welke knelpunten de ontwikkeling en verspreiding van innovaties belemmeren. Hierbij is het ook belangrijk om te identificeren welke activiteiten dienen te worden uitgefaseerd om het huidige dominante regime te destabiliseren, zoals processen waarbij fossiele brandstoffen worden gebruikt.

Door de zwak vervulde systeemfuncties verder te analyseren kunnen mogelijke beleidsaanbevelingen worden gegeven. De 'lock-in' waarin huidige gewoonten, wet- en regelgeving, actoren en infrastructuur elkaar in stand houden, kan zo worden opengebroken. Door het regime onder druk te zetten krijgen nieuwe innovaties en trajecten de ruimte, terwijl ondersteuning voor huidige initiatieven die de lock-in in stand houden wordt weggenomen. De resultaten worden besproken en gedeeld met de werkgroep innovatie in het kader van de duurzame luchtvaarttafel.

Geïnformeerde toestemming

Ik wil het interview graag opnemen, zodat ik deze achteraf nogmaals terug kan luisteren. Uw antwoorden worden vertrouwelijk behandeld en anoniem verwerkt in het verslag. Gaat u hiermee akkoord? Mocht u achteraf toch nog van gedachten veranderen, dan kunt u dit altijd laten weten. U mag uiteraard te allen tijde een vraag weigeren te beantwoorden.

Heeft u vooraf nog verdere vragen of opmerkingen? Ik ben bereikbaar onder telefoonnummer 06 21 32 31 57 of via julian.van.arkel@minienw.nl.

Interviewvragen

De volgende vragen gaan over de negen systeemfuncties van het missie-gedreven innovatiesysteem. Dit zijn de sleutelactiviteiten voor innovatie. Voor de transformatie naar duurzame luchtvaart is het belangrijk om te onderzoeken hoe we de ontwikkeling en verspreiding van innovatie kunnen versnellen, maar ook hoe het systeem kan worden gedestabiliseerd om oude (vervuilende) gebruiken uit te faseren. Mocht u bepaalde systeemfuncties niet volledig kunnen beantwoorden daar deze zich buiten uw werk en/of kennis terrein bevinden dan is dat uiteraard geen probleem.

Thema 1 - Experimenteren door ondernemers

Omschrijving 'experimenteren door ondernemers'	Ondernemers (zowel MKB'ers als grote bedrijven) spelen een cruciale rol in het innovatiesysteem door nieuwe technologie te verkennen, variaties te creëren in het ontwerp, het investeren van eigen middelen in de ontwikkeling van de technologie en uiteindelijk de opschaling van de technologie.
Voorbeelden	• Experimenteren om daarvan te leren. • Nieuwe technologieën verkennen en startups. • Variaties creëren in het (bestaande) ontwerp. • Nieuwe verdienmodellen en nieuwe markten betreden. • Investeren van eigen middelen in de ontwikkeling van technologie. • Opschalen van technologie en de productiecapaciteit.
(1.1) Op een schaal van 1 tot 5: in hoeverre is ondernemerschap toereikend rondom duurzame luchtvaart om de CO_2-reductie doelstellingen te kunnen behalen? *1 zwak ondernemerschap (weinig experimenteren), 5 sterk ondernemerschap (veel experimenteren)*	
(1.2) Wilt u uw antwoord onderbouwen/toelichten? 3 of lager, wat is de oorzaak of het achterliggende probleem? Hoe probeert men dit op te lossen? Als er geen oplossing is, wat zou een oplossing kunnen zijn? (bij 4) waarom is het geen 5?	

Thema 2 - Kennisontwikkeling

Omschrijving 'kennisontwikkeling'	Kennis betreffende nieuwe technologieën, producten, regels en de markt zijn nodig om te kunnen innoveren. Marktonderzoek, R&D en andere kennisontwikkelende activiteiten zijn hiervoor van groot belang.
Voorbeelden	• Research & Development activiteiten. • Met 'vallen en opstaan' nieuwe wegen ontdekken. • Wetenschappelijk onderzoek naar technologische en sociale/maatschappelijke oplossingen. • Ontwikkeling van kennis om CO_2 intensieve praktijken die het behalen van doelstellingen belemmeren versneld af te kunnen bouwen.
(2.1) Op een schaal van 1 tot 5: hoe beoordeelt u de ontwikkeling van kennis met betrekking tot de CO_2-reductie in het kader van duurzaam vliegen?	

(2.2) Op een schaal van 1 tot 5: hoe beoordeelt u de ontwikkeling van kennis om praktijken waarbij veel CO_2 wordt uitgestoten versneld af te bouwen, omdat deze het behalen van doelstellingen belemmeren? *1 weinig kennisontwikkeling, 5 veel kennisontwikkeling*
(2.3) Wilt u uw antwoorden onderbouwen/toelichten? Kunt u omschrijven in waar de kennisontwikkeling plaatsvindt in de sector? Welke activiteiten vinden voornamelijk plaats wat u verstaat onder kennisontwikkeling? 3 of lager, wat is de oorzaak of het achterliggende probleem? Hoe probeert met dit op te lossen? Als er geen oplossing is, wat zou een oplossing kunnen zijn? (bij 4) waarom is het geen 5?

Thema 3 - Kennisverspreiding

Omschrijving 'kennisverspreiding'	Om snel te innoveren is toegang nodig tot kennis. Daarom moet kennis uitgewisseld worden tussen partijen die geïnteresseerd zijn in het versnellen van de innovatie. Dit betreft zowel ondernemers als kennisinstellingen, maar ook NGO's, overheden en organisaties die kennis hebben van consumentengedrag.
Voorbeelden	• Kennisuitwisseling tussen partijen in de sector om oplossingen te ontwikkelen om zo gezamenlijk de doelstellingen te kunnen behalen. • Manieren waarop technologische en sociale kennis wordt verspreid/gedeeld over de problemen en oplossingen rond het behalen van de doelstellingen kunnen o.a. zijn: o Stakeholder meetings, conferenties, webinars, openbare raadplegingen, rapporteren van progressie.
(3.1) Op een schaal van 1 tot 5: hoeveel kennis verspreiding en deling is er tussen ondernemers, bedrijven, kennisinstellingen, NGO's en overheden? *1 weinig kennisverspreiding, 5 veel kennisverspreiding*	
(3.3) Wilt u uw antwoorden onderbouwen/toelichten? 3 of lager, wat is de oorzaak of het achterliggende probleem? Hoe probeert met dit op te lossen? Als er geen oplossing is, wat zou een oplossing kunnen zijn? (bij 4) waarom is het geen 5?	

Thema 4 - Richting geven aan de missie (directionaliteit)

(4.1) Hoe zou je het functioneren van de duurzame luchtvaarttafel vanuit jouw perspectief omschrijven?

Thema 4a - Prioritering van duurzaamheid (*Probleem-directionaliteit*)

Omschrijving 'probleem-directionaliteit'	Duurzaamheid is een van de vele maatschappelijke vraagstukken/uitdagingen, waarmee organisaties die actief zijn in de luchtvaartsector mee te maken hebben in hun dagelijkse bedrijfsvoering. Niet ieder onderwerp kan evenveel prioriteit krijgen. Dit kan mogelijk impact hebben op het behalen van de CO_2-reductie doelstellingen.
Voorbeelden	• Prioriteit op de agenda van duurzaamheid (CO_2-reductie) ten opzichte van andere publieke belangen zoals veiligheid, verbindingen (economisch) en leefbaarheid (geluid, lokale luchtvervuiling). • Mogelijke andere onderwerpen die vanuit uw perceptie belangrijk zijn en een hoge prioriteit hebben tegenover duurzaamheid (CO_2-reductie).
(4a.1) Op een schaal van 1 tot 5: in hoeverre wordt er vanuit uw perceptie prioriteit gegeven aan duurzame luchtvaart (CO_2-reductie doelstellingen) in relatie tot andere relevante maatschappelijke uitdagingen/vraagstukken? *1 lage prioriteit verduurzaming, 5 hoge prioriteit verduurzaming*	
(4a.2) Wilt u uw antwoord onderbouwen/toelichten? (4a.3) Waar zitten de knelpunten? Waarom is dit zo? Hoe komt dit? (4a.4) Wat is de oorzaak of het achterliggende probleem? (4a.5) Heeft u dan het idee dat de hele sector hetzelfde bedoeld als we het over verduurzaming van de luchtvaart hebben? (4a.6) Hoe doet Nederland het in vergelijking met andere landen om ons heen? 3 of lager, wat is de oorzaak of het achterliggende probleem? Hoe probeert met dit op te lossen? Als er geen oplossing is, wat zou een oplossing kunnen zijn? (bij 4) waarom is het geen 5?	

Thema 4b - Prioriteren van oplossingsrichtingen (*Oplossing-directionaliteit*)

Omschrijving 'oplossing-directionaliteit'	Wanneer er sprake is van een sterke oplossing-directionaliteit, dan betekent dit dat er consensus ontstaat over de richting waar men naar toe wil. Innovatie is per definitie onzeker, maar wordt vergemakkelijkt indien er eenduidige verwachtingen zijn over de toekomstige vormgeving. Hierdoor neemt de risicoperceptie af en gaan meer actoren deelnemen aan het innovatiesysteem. Richting geven kan heel generiek zijn – "de toekomstige luchtvaart moet duurzaam zijn" – of heel specifiek – "Technologie A gaat een belangrijke rol spelen in de verduurzaming van de luchtvaart". Het opdelen van het gelimiteerde menselijk en financieel kapitaal over de grote verscheidenheid aan trajecten leidt niet tot versnelling van de transitie. Dit kan leiden tot richtingloosheid waar oplossingen die onvoldoende worden doorontwikkeld om het regime te veranderen resulteren in een zwakke oplossing-directionaliteit.
Voorbeelden	• Prioritering van potentiële oplossingen die bijdragen aan CO_2-reductie. • Bewust van de afhankelijkheden tussen oplossingen en worden deze mogelijkheden benut? (Bijv. technologie X heeft invloed op technologie Y).

	• Ondersteuning voor oplossingen die bijdragen aan het uitfaseren van praktijken waarbij veel CO_2 wordt uitgestoten.

(4b.1) Op een schaal van 1 tot 5: hoeveel richting is er in de sector en consensus tussen partijen over welke oplossingen prioriteit krijgen om de CO_2-reductie doelstellingen te kunnen behalen? *1 zwakke oplossing-directionaliteit, 5 sterke oplossing-directionaliteit*
(4b.2) Wilt u uw antwoord onderbouwen/toelichten? (4b.3) (4b.4) 3 of lager, wat is de oorzaak of het achterliggende probleem? Hoe probeert met dit op te lossen? Als er geen oplossing is, wat zou een oplossing kunnen zijn? (bij 4) waarom is het geen 5?

Thema 4c - Monitoren, reflectie en aanpassingsvermogen (*Reflexiviteit*)

Omschrijving 'reflexiviteit'	Reflexief monitoren, anticiperen, evalueren en impact assessment procedures leveren een analytische en vooruitkijkende blik om het innovatiesysteem in de juiste richting te sturen in het kader van probleem framing, het zoeken naar nieuwe oplossingen op basis van lessen getrokken uit het verleden en veranderende context. Dit kan worden gezien als een 2e niveau van directionaliteit.
Voorbeelden	• Monitoren, evalueren, anticiperen, rapporteren of een impact assessment van het beleid. • Onafhankelijk (bijv. door onafhankelijke partij) en transparant. • Bijsturen indien noodzakelijk om de doelen te kunnen behalen.

(4c.1) Op een schaal van 1 tot 5: hoe sterk wordt de progressie geëvalueerd en wordt er bijgestuurd indien noodzakelijk om de CO_2-reductie doelstellingen te kunnen behalen? *1 zwakke reflexiviteit, 5 sterke reflexiviteit*
(4c.2) Wilt u uw antwoord onderbouwen/toelichten? 3 of lager, wat is de oorzaak of het achterliggende probleem? Hoe probeert met dit op te lossen? Als er geen oplossing is, wat zou een oplossing kunnen zijn? (bij 4) waarom is het geen 5?

Thema 5 - Markten creëren en destabiliseren

Omschrijving 'markten creëren en destabiliseren'	Voor innovatie is het van belang dat nieuwe markten kunnen worden gecreëerd om zo technologische en sociale innovaties die bijdragen aan de CO_2-reductie te kunnen opschalen én te kunnen ondersteunen. Tegelijk is het van belang dat bestaande markten waarbij veel CO_2 wordt uitgestoten versneld worden afgebouwd, omdat deze het behalen van doelstellingen belemmeren; dit is het destabiliseren van het regime.
Voorbeelden	• Vraag vanuit de sector voor innovatieve oplossingen. • Ondersteuning voor het creëren van niche markten.

	• Ondersteuning om op te schalen. • Destabiliserend beleid: vliegbelasting. • Uitfaseren van activiteiten die veel CO_2 uitstoten.
(5.1) Op een schaal van 1 tot 5: hoe sterk beoordeelt u hoe de aantrekkelijkheid van de markt om de ontwikkeling en verspreiding van innovaties te bevorderen die bijdragen aan de CO_2-reductie doelstellingen? *1 weinig marktcreatie, 5 veel marktcreatie* (5.2) Op een schaal van 1 tot 5: hoe sterk beoordeelt u de destabilisatie van bestaande markten waarbij veel CO_2 wordt uitgestoten die het behalen van de doelstellingen mogelijk belemmerd? *1 zwakke destabilisatie, 5 sterke destabilisatie*	
(5.3) Wilt u uw antwoorden onderbouwen/toelichten? 3 of lager, wat is de oorzaak of het achterliggende probleem? Hoe probeert met dit op te lossen? Als er geen oplossing is, wat zou een oplossing kunnen zijn? (bij 4) waarom is het geen 5?	

Thema 6 - (De)mobiliseren van middelen

Omschrijving '(de)mobiliseren van middelen'	Om te innoveren zijn middelen nodig. Hierbij wordt onderscheid gemaakt tussen financiële middelen, en menselijk kapitaal in de vorm van opgeleide mensen en materialen zoals de beschikbaarheid van grondstoffen.
Voorbeelden	• Financiële middelen • Menselijk kapitaal • Materialen zoals grondstoffen • Weghalen van middelen bij CO_2 intensieve praktijken
(6.1) Op een schaal van 1 tot 5: hoe beoordeelt u de beschikbaarheid van middelen vanuit uw organisatie/uw perceptie om bij te dragen aan CO_2-reductie van de luchtvaart? *1 weinig beschikbare middelen, 5 veel beschikbare middelen* (6.2) Op een schaal van 1 tot 5: worden er middelen vanuit uw organisatie/perceptie gezien weggehaald bij CO_2 intensieve praktijken? *1 weinig weghalen van middelen, 5 veel weghalen van middelen*	
(6.3) Wilt u uw antwoorden onderbouwen/toelichten? 3 of lager, wat is de oorzaak of het achterliggende probleem? Hoe probeert met dit op te lossen? Als er geen oplossing is, wat zou een oplossing kunnen zijn? (bij 4) waarom is het geen 5?	

Thema 7 – Tegengaan van weerstand

<table>
<tr><td>Omschrijving ‘tegengaan van weerstand’'</td><td>Vernieuwing kan weerstand oproepen. Om weerstand tegen te gaan en meer legitimiteit voor duurzame luchtvaart te kunnen creëren, moet de huidige status quo doorbroken worden. Het huidige systeem bestaat uit een constellatie van gewoontes en gebruiken, wet- en regelgeving, actoren en infrastructuur die elkaar versterken en in stand houden. In deze situatie is er weinig draagvlak voor vaak dure (en, in eerste instantie nog) inferieure technologieën. In de innovatie literatuur heet dit een ‘lock-in’.

Om de ontwikkeling en verspreiding van innovatie te versnellen, is het van belang de prioriteit van de verduurzaming van de luchtvaart hoger op de agenda te plaatsen. Het is ook van belang dat de verschillende oplossingen die bijdragen aan CO_2-reductie meer aandacht krijgen. Hierdoor krijgen zowel het onderwerp verduurzaming als de verschillende oplossingen die hier aan bijdragen meer legitimiteit. Tegelijk is het van belang om de ‘lock-in’ te doorbreken. Hierbij wordt legitimiteit verwijderd bij praktijken waarbij veel CO_2 wordt geproduceerd.</td></tr>
<tr><td>Voorbeelden</td><td>• Weerstand tegen de groei van de luchtvaart
• Duurzaamheid hoger op de agenda
• Steun betuigen aan bepaalde duurzame technologieën/ontwikkelingen (lobby/belangengroepen)
• Maatschappelijk draagvlak creëren</td></tr>
<tr><td colspan="2">(7.1) Op een schaal van 1 tot 5: in welke mate wordt er weerstand doorbroken om meer legitimiteit voor de verduurzaming van de luchtvaart te creëren voor het behalen van de CO_2-reductie doelstellingen?

1 weinig legitimiteit/veel weerstand, 5 veel legitimiteit/weinig weerstand

(7.2) Welke oplossingen ter verduurzaming van de luchtvaart krijgen vanuit uw perceptie de meeste ondersteuning en welke de meeste weerstand?</td></tr>
<tr><td colspan="2">(7.3) Wilt u uw antwoorden onderbouwen/toelichten?

3 of lager, wat is de oorzaak of het achterliggende probleem?
Hoe probeert met dit op te lossen?
Als er geen oplossing is, wat zou een oplossing kunnen zijn?
(bij 4) waarom is het geen 5?</td></tr>
</table>

Aanvullende systeem problemen

(8) Zijn er volgens u nog andere knelpunten die ook van invloed zijn op de verduurzaming van de luchtvaart om zo de CO_2-reductie doelstellingen te kunnen behalen?

Appendix VII – Intercoder reliability check

```
Run MATRIX procedure:

Krippendorff's Alpha Reliability Estimate


             Alpha    LL95%CI    UL95%CI      Units   Observrs      Pairs
Nominal      ,8376      ,7880      ,8872    25,0000     5,0000   250,0000

Probability (q) of failure to achieve an alpha of at least alphamin:
   alphamin         q
      ,9000      ,9934
      ,8000      ,0665
      ,7000      ,0000
      ,6700      ,0000
      ,6000      ,0000
      ,5000      ,0000

Number of bootstrap samples:
  10000

Judges used in these computations:
 obs1     obs2     obs3     obs4     obs5

Examine output for SPSS errors and do not interpret if any are found

------ END MATRIX -----
```