Breaking the Blend Wall

A systematic deconstruction of barriers to the regional adoption of Sustainable Aviation Fuel

Master Thesis

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by

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Preface

Six years of academic endeavours at TU Delft finally come to a close with the publishing of this thesis, and what a journey it has been. Although the path was not straightforward, it was one full of insights and skills that will harness me for the future to come and has culminated in the form of this paper. Of course, this would not have been possible with the many people who have supported me in this process.

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Second, I want to thank the LDE Thesis Lab coordinators Ingeborg de Pater, Pieter-Jan Proesmans, and Prem Sundamoorthy alongside Flying Vision Accelerator (FVA) coordinators Elise Bavelaar and Victor Rijkaart for their support during the research process. As the coordinators for our cluster Sustainable Aviation: Wings of the Future, they helped me broaden my perspective by enabling collaboration across disciplines with other students in our consortium. Furthermore, their help in further interaction with the industry greatly enriched the quality of this research, for which I am deeply grateful.

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Luke Willigenburg
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Abstract

The aviation sector is one of the largest sources of greenhouse gas (GHG) emissions, accounting for 2% of global CO_2 emissions in 2022, with emissions potentially tripling by 2050 without intervention. In light of these events, the most promising avenue to cut emissions is through the use of Sustainable Aviation Fuels (SAF), although its impact remains limited due to numerous barriers that do not allow SAF blend ratios above 50%. Therefore, the main objective of this research is to systematically investigate the current barriers to blending limits of SAF specified under existing regulations and develop a comprehensive strategy which mobilises stakeholders. While existing literature addresses future uptake of SAF blends, identified barriers and coupled strategies are unclear, underdeveloped and dispersed, with regulatory mechanisms at times inefficacious. Furthermore, although collaboration among stakeholders is encouraged, it is unclear what roles individual stakeholders should take on to approach certain problems. If barriers can be systematically identified and managed, the effectiveness of SAF could significantly increase, promoting wider market adoption of SAF and furthering the aviation sector's goals in reducing its emissions. Simultaneously, this research can prove useful for policy-makers in addressing systemic barriers in sustainability transitions.

The research was conducted using a qualitative approach. The sample was composed of 14 specialists ranging from different key stakeholder groups. These key stakeholder groups were largely located in the higher rungs of the participation continuum, a model used in the stakeholder analysis which placed stakeholders along the continuum based on their level of participation in the SAF ecosystem. Semi-structured interviews then collected data, which were translated into codes. Using the Technological Innovation System (TIS) and its seven building blocks as a framework, all identified codes were grouped under one of the TIS building blocks as shown in Figure 1. Provided this, three analyses were performed in parallel: barriers of SAF blending were identified, SAF production methods were compared against one another based on method-specific barriers, and strategic measures were formulated to overcome identified barriers alongside the actors who are responsible for enacting them. This, however, deviated from the TIS framework in the sense that it formulated a strategy for an entire industry and how stakeholders can collaborate as opposed to the formulation of a strategy for a single firm.

SAF blending above 50% is found to hold little to no priority among the SAF industry, which rather prioritizes upscaling of available capacity. This is because there is currently too little blend component available to achieve high blend percentages, regulatory limits do not instil an urgency to increase blends due to being small in number, and SAF supply methodologies are configured such that all SAF is blended to the bare minimum mandated. Only when such barriers are removed, and more blend component becomes available in the future, an increase in blend ratios and removal of the blend wall will be necessitated to achieve a higher sustainability impact of SAF in flight.

For SAF itself, it is found that the majority of TIS building blocks remain incompatible or partly incompatible. Product performance and quality are sufficient to some degree given that SAF can already be used in existing aircraft, but remains limited to blends of 50%. Furthermore, uncertainties in production concerning feedstock variability and blending dynamics require suppliers to use sufficient margins. Product price is largely incompatible, the most cost-efficient SAF still being at least twice as expensive as conventional fuel due to energy-intensive processes and lack of technological maturity. Furthermore, price levels are highly volatile. The production system is similarly incompatible, projected to produce insufficient quantities of bio-SAF and e-SAF by 2030 due to long construction times and limited financial resources. Institutions and regulations are partly incompatible as they are widely in place but remain scattered and unclear. Due to regulatory fragmentation, there are structural inefficiencies and regulatory burdens in the SAF industry, which amount to a poor market climate. The same holds for network formation and coordination, with limited participation and coordination concerning sustainability transitions despite many collaboration processes in place. Uptake among customers remains limited, too,

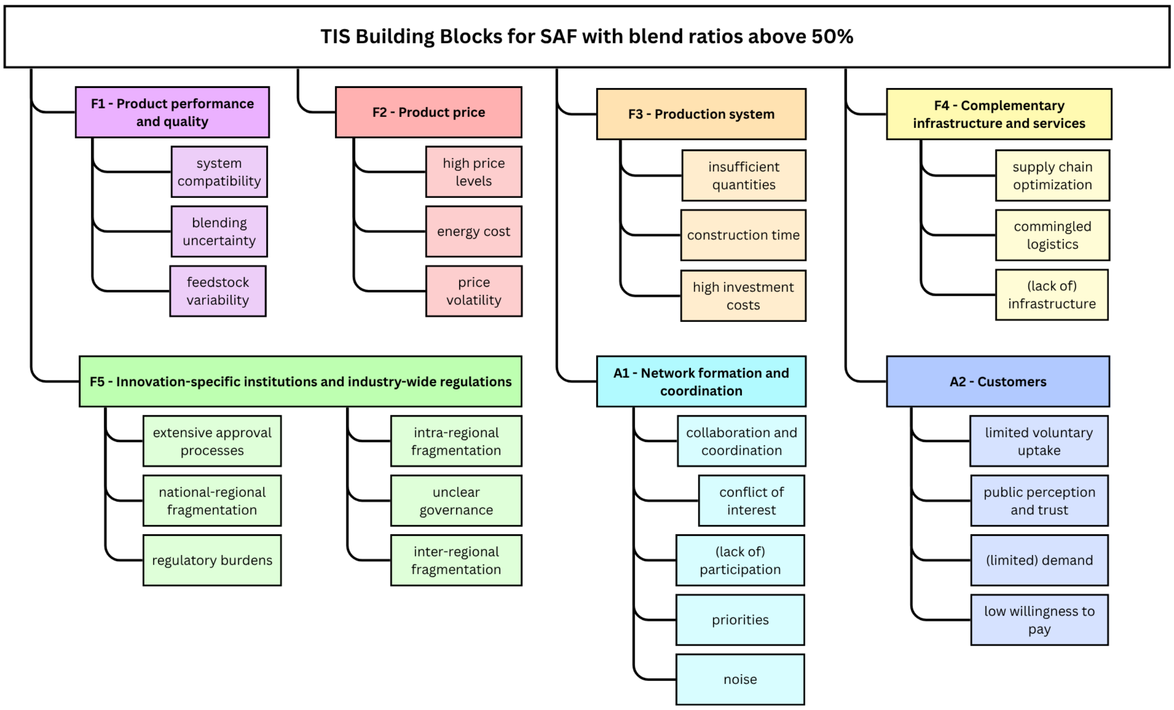


Figure 1: Overview of interview codes grouped under each TIS building block

attributed to their lack of knowledge and trust in SAF combined with the limited means by airlines to communicate. Only complementary infrastructure and services are fully compatible, as qualified SAF can use the same means of transport as conventional fuel.

In terms of comparison between production methods, hydro-processed esters and fatty acids (HEFA) performs the best concerning product price and production system because it is a more mature technology. On the other hand, alcohol-to-jet (ATJ), catalytic hydrothermolysis jet (CHJ), and Fischer-Tropsch (FT) are still underdeveloped and more expensive, yet fall under the same mandated share of bio-SAF as HEFA, which causes them to be minimally stimulated. However, given HEFA's limited impact due to its feedstock constraints, FT, ATJ, and CHJ technologies show future promise because they hold more potential with respect to unlocking the blend limit and have a larger pool of feedstock available. The same holds for synthetic SAF (e-SAF), although its energy-intensive processes remain a large bottleneck for future upscaling. Promising developments in this front concern methanol-to-jet (MTJ), which allows production of e-SAF through a larger pool of available feedstocks.

Paired with each identified key challenge comes an array of measures and actors that enables the industry to overcome these challenges. Mandates and regulations alongside incentives and subsidies most commonly contribute to bridging challenges concerning price, production system, and regulations. Meanwhile, product quality, performance, and infrastructure require further developments in technology and designated infrastructure to alleviate bottlenecks. As for network formation, stakeholder coordination, and customers, emphasis is more often placed on knowledge building and sharing, networking, and raising awareness. Then, depending on the context of the challenges and coupled measures, different levels of participation are required among stakeholders.

From these findings, the research reveals a comprehensive overview of barriers to large-scale SAF adoption. The application of the TIS framework in a multi-actor system broadens the perspective on barriers and strategies beyond the level of individual firms, illustrating that the strategies to help overcome the barriers are not enacted by a single stakeholder. Instead, to achieve the successful introduction of SAF, dynamic collaboration and coordination within the industry are required, with each stakeholder fulfilling different roles when faced with different challenges.

Contents

Nomenclature

Abbreviation	Definition
ASP	Amsterdam Schiphol Pipeline
ASTM	American Society for Testing and Materials
ATJ	Alcohol-To-Jet
CAF	Conventional Aviation Fuel
CEPS	Central European Pipeline System
CfD	Contracts for Difference
CHJ	Catalytic Hydrothermolysis Jet
CO_2	Carbon Dioxide
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
EASA	European Union Aviation Safety Agency
ETS	Emission Trading System
EU	European Union
FAA	Federal Aviation Administration
FT	Fischer-Tropsch
FRL	Fuel Readiness Level
GHG	Greenhouse Gas
HEFA	Hydro-processed Esters and Fatty Acids
IC	Influencing Condition
ICAO	International Civil Aviation Organization
LCA	Life Cycle Assessment
MTJ	Methanol-To-Jet
OEM	Original Equipment Manufacturer
PTL	Power-To-Liquids
RED	Renewable Energy Directive
RTHA	Rotterdam The Hague Airport
SAF	Sustainable Aviation Fuel
SAK / SKA	Synthetic Aromatic Kerosene
SBC	Synthetic Blend Component
SPK	Synethetic Paraffinic Kerosene
SCS	Sustainability Certification Scheme
TIS	Technological Innovation System
TRL	Technology Readiness Level
UCO	Used Cooking Oil
US	United States

1 Introduction

In 2022, the aviation sector accounted for 2% of global carbon dioxide (CO_2) emissions and approximately 4% of total EU greenhouse gas (GHG) emissions, making it the second-largest source of GHG emissions after road transport. Without intervention, emissions could triple by 2050 (European Commission, 2025). To prevent rising temperature levels and decrease the effects of climate change, it has been agreed upon at the 2015 Paris Agreement to reduce GHG emissions in 2030 and achieve net-zero emissions in 2050 (United Nations, 2025). In light of these events, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) initiative has been implemented by the International Civil Aviation Organization (ICAO) to reduce CO_2 emissions by 5% in international aviation (ICAO, 2026). CORSIA demands the use of carbon credits or alternative low-carbon fuels to reduce the growth of emissions. An example of the latter has been widely discussed and already implemented in the aviation sector, namely, sustainable aviation fuels (SAF).

SAF are defined by the ICAO as ”renewable or waste-derived aviation fuels that meet sustainability criteria” (ICAO, 2026). SAF have the greatest potential to reduce CO_2 emissions in international aviation (International Civil Aviation Organization, 2022) and could replace up to 10% of total European jet fuel consumption by 2030 (World Economic Forum, 2021). Across the globe, 556 renewable fuel facilities have been announced, of which 63 are currently in operation producing SAF with a total capacity of 5.45 Mt (ICAO, 2026).

Although SAF show promising signs as alternative aviation fuels, there are also limitations. Aviation fuel specifications installed by the American Society for Testing and Materials (ASTM) allow for a maximum of 50% blending of synthetic blending components (SBCs) with conventional aviation fuels (CAF) such as Jet A-1, primarily driven by the minimum required aromatic content of 8%. With an aromatic content of 15 to 20%, no less than 50% of Jet A-1 must be blended with SAF to be safely compatible with current aircraft technology (ASTM International, 2023; European Commission, 2026). However, recent studies have shown that for a given amount of SAF, a higher SAF blend used for a single flight leads to a reduction by a tenfold in climate impact when compared to low SAF blends used for multiple flights (Teoh et al., 2022). European Union (EU) mandates such as ReFuelEU aviation call for an increase in blend ratios of up to 70% by 2050 to achieve the full potential of SAF (European Commission, 2026), but this cannot yet be achieved due to the imposed regulations. This is not a challenge exclusive to SAF, but can be generalized to many regulations and certification specifications which hinder technological development.

Existing literature addresses a multitude of concerns to support the uptake of SAF blends. However, as is further elaborated upon in section 2.4, strategies are underdeveloped and dispersed, with regulatory mechanisms at times inefficacious. The link between barriers to SAF blending and their proposed solutions is often unclear, nor does any comparative analysis between barriers exist, from which future decision-making suffers. Although literature establishes that complex barriers can only be surmounted by the collaboration of stakeholders, it is unclear what roles individual stakeholders should take on to approach certain problems.

Therefore, the objective of this research is to systematically investigate the current barriers to blending limits of SAF specified under existing regulations and develop a comprehensive strategy which mobilises stakeholders to help overcome these barriers on both the short and long term. If the barriers can be identified and managed, the effectiveness of SAF could significantly increase, promoting wider market adoption of SAF and furthering the aviation sector's goals in reducing its emissions and becoming more sustainable. Simultaneously, this research can prove useful for policy-makers in addressing systemic barriers in sustainability transitions.

Given above, the main research question of this thesis is as follows:

> ***"What roles can individual stakeholders fulfil to facilitate the transition toward higher sustainable aviation fuel (SAF) blend ratios?"***

The sub-questions derived from the main research question are listed below:

- **RQ1:** Which stakeholders are involved in the transition toward higher SAF blend ratios?
- **RQ2:** What types of barriers currently prevent SAF blending beyond 50%, and do these barriers differ across synthetic blending components?
- **RQ3:** Which technical, regulatory, and market-related measures could enable SAF blending beyond the current limit?

To answer the main research question, this research utilises the Technological Innovation System (TIS) framework to explore pathway-specific barriers to higher blend ratios of SAF. Based on the inputs of the model - the barriers and the influencing conditions - a strategy can be formulated, which serves as the output of the model. To achieve this, a qualitative approach identifies, categorises, and compares barriers across a select group of 14 specialists in the alternative aviation fuel industry. This research approach is outlined in chapter 3 and worked out in the following chapters. First, to simultaneously answer RQ1 and ensure that the sample will be representative for answering the main research question, chapter 4 helps gain more insight into the SAF industry and assess who would be able to facilitate a technological transition to higher SAF blends. Thereafter, by means of semi-structured interviews, several barriers and influencing conditions are identified in chapter 5 to be summarized in a thematic network. In addition, a comparative analysis in chapter 6 will be performed between certain SAF pathways to highlight the future potential of one over another. Combined with the thematic network, these inputs effectively answer RQ2. Finally, based on the inputs and findings from proposed measures and stakeholder participation, strategic measures will be formulated in chapter 7, answering RQ3.

2
Literature Review

In the following chapter, related literature is explored to gain an understanding of the current state of research. The three sub-questions and the main research question are discussed in section 2.1, section 2.2, and section 2.3. After establishing the current state of research, a knowledge gap is discussed in section 2.4 that needs to be further explored to bridge the gap to the desired state of research.

2.1. Pathway-specific barriers to increased SAF blending

A theoretical background for Sustainable Aviation Fuels (SAF) and its environmental benefits has already been largely established in the literature. Also known as drop-in fuels, SAF have different production methods or 'pathways' dependent on types of feedstock and technology used. Pathways discussed are either those that are certified for use (Ding et al., 2026; Mariyam et al., 2026), hold a high Technology Readiness Level (TRL) (Bauen et al., 2020), or a combination of both (Uddin & Wang, 2025). Common surface-level pathways discussed are alcohol-to-jet (ATJ), Fischer-Tropsch (FT), hydro-processed esters and fatty acids (HEFA), and power-to-liquids (PTL). In terms of barriers to SAF adoption, the blending limitations set by the American Society for Testing and Materials' (ASTM) specifications are just the tip of the iceberg. Within the literature, complex barriers that constrain further application of high-blend SAF are diverse, but barriers can be grouped together. In the following paragraphs, technological, economic, environmental, and regulatory challenges (Ding et al., 2026; Reisdorf et al., 2025; Uddin & Wang, 2025; Vishwakarma, 2025) are respectively discussed.

First, technological challenges that drive up SAF procurement costs comprise underdeveloped industrial procedures used to transform feedstock (Ding et al., 2026; Uddin & Wang, 2025) or scale production capacity (Vishwakarma, 2025). Low "SAF yields" (Ding et al., 2026) are a result of variability in feedstock impacting quality and uniformity of SAF, as well as limited energy efficiency of SAF production (Uddin & Wang, 2025). Ding et al. (2026) extends these factors dependent on the type of SAF pathway, distinguishing between optimal, moderate, and poor production conditions based on feedstock purity and composition, conversion efficiencies, and/or process efficiencies.

Second, economic challenges concern high SAF production costs relative to conventional aviation fuels (CAF), continued supply of capital for development efforts, efficacious government-supported incentives and subsidies, and competitiveness in the aviation fuel market (Uddin & Wang, 2025). High production costs may result from aforementioned technological challenges, but may also stem from increased transportation costs (Vishwakarma, 2025) or cumbersome certification processes (Ding et al., 2026).

Third, while SAF is noted as an "escape route" when slashing emissions of greenhouse gas (GHG), carbon dioxide (CO_2), and particulate matter (Uddin & Wang, 2025), broader ecological impacts of SAF pose an environmental challenge due to uncertainties in the Life Cycle Assessment (LCA). Ding et al. (2026) agrees, noting that accurately quantifying and verifying emission reductions along the whole life cycle of SAF is complex, and the results of certification may not be uniform across different certification bodies recognized by the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). Simultaneously, some requirements pertaining to biodiversity conservation or food security assurance suffer from ambiguity, making it difficult to assess whether the SAF pathway complies with these requirements. This verification, however, is critical for a multitude of actors: for airlines who require certified SAF, for investors and financial institutions who demand compliance before committing capital, and for consumers and civil society who increasingly scrutinize aviation's climate claims. Reisdorf et al. (2025) further notes that, although customers prioritize sustainability, they have a low willingness to pay the added costs, also due to scepticism stemming from previous environmental scandals.

Finally, the testing and validation process of new aviation fuels, installed to ensure the safety of aircraft during flight, creates a regulatory barrier. According to Uddin and Wang (2025), Vishwakarma (2025), and Ding et al. (2026), this barrier is caused by fragmented regulatory regimes and policy-making, resulting in an absence of well-defined standards. Meanwhile, the limited number of existing technical standards requires long certification cycles, high certification costs, large amounts of fuel to undergo testing, and cooperation with qualified equipment manufacturers (Ding et al., 2026; Uddin & Wang, 2025). As Ding et al. (2026) notes, failure to achieve certification results in significant financial losses, making the development of new pathways increasingly risky. However, pressure is simultaneously exercised on airlines, which may create a divergent playing field: European Union (EU) SAF mandates such as ReFuelEU aviation have a significant influence on airline competitiveness, because airlines based in non-EU regions face lower operational costs, disadvantaging carriers operating under stricter regulations (Reisdorf et al., 2025). Furthermore, some regulations impose logistical constraints, requiring the use of designated transport to bring SAF to the airport (Ahmad & Xu, 2021).

Concerning pathway-specific barriers, a limited number of articles extensively quantify metrics for a wide range of pathways. Ding et al. (2026) performs a comparative analysis between appropriate groups of pathways based on yield, feedstock output, minimum fuel selling price (MFSP), GHG emission reduction potential, geographic adaptability in developing countries, and Fuel Readiness Level (FRL). Meanwhile, Mariyam et al. (2026) tabulates and compares all CORSIA-approved SAF pathways based on feedstock type, TRL, process flow and corresponding energy conversion rate, MFSP, and CO_2 reduction potential. Although there are some striking similarities, there is no single set of metrics defined for assessing pathways. Furthermore, both similarities and discrepancies can be found between articles. According to Ding et al. (2026) and Mariyam et al. (2026), HEFA technology demonstrates the highest technological maturity with both a TRL and FRL of 9. While capable of being produced at a commercial scale, further scalability is limited by feedstock availability and sustainability concerns. However, whereas Mariyam et al. (2026) finds that HEFA has the lowest minimum selling price, Ding et al. (2026) notes the opposite, rather labelling the cost metric as "suboptimal".

2.2. Policy measures and strategies for SAF adoption

To combat such challenges, policy measures and strategies for an increased adoption of SAF have been recommended. Raihan (2025) provides a general overview of institutions that have developed policies that currently support SAF adoption, namely, the International Civil Aviation Organization's (ICAO) CORSIA, the EU's ReFuelEU aviation, Emission Trading System (ETS), and Net-Zero Industry Act (NZIA), and the United States' Continuous Lower Energy, Emissions, and Noise (CLEEN) program and the SAF Grand Challenge. Despite these policies, Mariyam et al. (2026) posits that "regional differences remain that shape the pace and scale of implementation", emphasising Asian countries lagging with limited regulatory mechanisms. Although regions with strong mandates or incentives advance more rapidly (Mariyam et al., 2026), they face higher operational costs than airlines under less stringent regulations, making it increasingly difficult to compete on the international market (Reisdorf et al., 2025). Altogether, this slows global scaling. Moreover, Mariyam et al. (2026) argues that policies focus on production-related activities, while neglecting demand-related mechanisms. This is affirmed by proposed solutions found in the literature, such as optimizing production techniques and novel pathways through increased collaborative efforts between industry and academia (Uddin & Wang, 2025) or guaranteeing availability of SAF on the market through long-term partnerships (Vishwakarma, 2025). Regardless of the challenges that policy-making faces, it can be concluded that adoption barriers are best tackled by a multitude of actors due to their complexity and interconnectedness.

2.3. Stakeholder collaboration and levels of participation

As Vishwakarma (2025) emphasises, SAF's complex barriers can only be surmounted by the collaboration and participation of - among others - industry and government stakeholders. Although this consensus is established in SAF literature, it is unclear what roles individual stakeholders should take on to approach certain problems, nor is it unclear to what degree they should get involved. This gap is bridged in policy analysis, where, for example Carrera et al. (2021) models collaboration as an iterative and interactive process of four key pillars: stakeholder participation, stakeholder negotiation, the level of uncertainty and consensus among stakeholders, and computer-based models.

Stakeholder participation and negotiation are often intertwined. Together, they define the structure for interaction between stakeholders to enhance commitment and engagement, distinguishing between levels of participation and cooperation. It is through this co-creation process, as Kazadi et al. (2016) notes, that organizations build new knowledge and consequently create value. However, co-creation processes also face challenges such as conflicts due to stakeholder diversity. An analysis of stakeholders and the dynamic relationships between them to attain a quality of communication that builds consensus and manages conflicts warrants partnership success (Carrera et al., 2021). This is also agreed upon by Luyet et al. (2012), who proposes a similar framework that first identifies, characterizes, and categorizes stakeholders in order to appoint a specific degree of participation and corresponding participatory technique dependent on the degree of involvement. Lieu et al. (2019) extends this view by noting that, although a consensus-building engagement process (CBEP) may prolong the overall process, it is required at each step of the project for building long-term relationships. CBEP helps achieve true inclusion of actors in climate change policies and reduces risks of negative outcomes. Alternatively, an equitable knowledge co-production framework can help reflect on the development process, maintaining epistemic justice and considering recognition across all stakeholders (Lieu et al., 2023).

Carrera et al. (2021) continues, stating the level of uncertainty and consensus affects the structure and complexity of the system, and will influence how collaborations are shaped. Recently, this is more often referred to in the literature as a ”wicked problem” (Levin et al., 2012; Rittel & Webber, 1973; Wanzenböck et al., 2020). The problem is hard to define with no definitive formulation or clear stopping rule, its complexity extending to the solution space as proposed solutions create new complications. Despite many stakeholders with conflicting interests and views being involved, there is a lack of central authority. Wanzenböck et al. (2020) offers a framework to deal with such wickedness, differentiating between divergent and convergent views on the problem and solution space. The divergence of a space is based on the three dimensions of wickedness - contestation, complexity, and uncertainty - from which a mission-oriented innovation policy (MIP) can consequently be derived.

Finally, Carrera et al. (2021) notes that computer-based models are the means to provide informed decision-making through existing models, tools, and technologies. They support the analysis, generation, and preparation of evidence-based strategies and policies.

2.4. Literature gap

While existing literature addresses a multitude of concerns to support the commercial deployment of SAF, strategies that help break down barriers of complex nature are underdeveloped and dispersed, with regulatory mechanisms at times contributing to the wickedness of the problem. There is often no direct link drawn in literature between multiple barriers and their proposed solutions, allowing room for ambiguity of whether the solution space is appropriately modelled for the problem space. Furthermore, there is a lack of comparative analysis performed between barriers, from which future decision-making suffers. Finally, even though literature establishes that complex barriers can only be surmounted by the collaboration and participation of stakeholders, it is unclear what roles individual stakeholders should take on to approach certain problems, nor is it unclear to what degree they should get involved.

Therefore, future research is necessitated to systematically investigate the current barriers to blending limits of SAF specified under existing regulations and develop a comprehensive strategy which mobilises stakeholders to help overcome these barriers on both the short and long term. This also relates back to the main research question to investigate what roles stakeholders can fulfil to facilitate the transition toward higher SAF blend ratios.

3 Methodology

This research utilises the Technological Innovation System (TIS) framework to explore pathway-specific barriers to higher blend ratios of sustainable aviation fuels (SAF) and answer the main research question. This framework and any deviations from the model are further discussed in section 3.1. To be able to use the TIS framework to answer the main research question, the research design is tuned accordingly in section 3.2, accompanied by a corresponding sample strategy, data collection method, and data analysis. This describes the procedure of preparing, collecting, and analysing data to arrive at the required inputs of the TIS framework, and consequently its outputs.

3.1. Theoretical framework

To systematically identify and develop strategies to remove barriers, the TIS framework initially developed by Carlsson and Stankiewicz (1991) was used. They define a TIS as ”a dynamic network of agents [...] under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology”. Rather than the framework developed by Carlsson and Stankiewicz (1991), however, the TIS framework adopted by Ortt and Kamp (2022) was selected as it introduces a managerial perspective to existing technology transition literature and proposes a methodology for adopting certain introduction strategies. Furthermore, Ortt and Kamp (2022) focuses on niche, radically new technological innovations, which made it more suitable to the topic of high-blend SAF.

This framework departs from the typical grouping of barriers under technological, economic, environmental, or regulatory problems, rather assessing an innovation from a system point-of-view. A TIS is composed of seven building blocks that all need to be present to enable large-scale diffusion (Ortt & Kamp, 2022).

1. **Product performance and quality**: A product with sufficient performance and quality relative to competitive products.
2. **Product price**: a product with sufficient price levels relative to competitive products.
3. **Production system**: a production system which can produce sufficient quantities of the product relative to competitive products.
4. **Complementary products and services**: products and services which add value in one or multiple product lifecycle phases.
5. **Network formation and coordination**: actors and the coordination among them to guide the product through its lifecycle.
6. **Customers**: potential customer segments that have sufficient knowledge, means, and willingness to acquire and use the product.
7. **Innovation-specific institutions**: policies, laws, and regulations describing norms and requirements regarding the product, its production system, complementary products and services, and/or actor and customer interaction with the product.

In addition to the building blocks, there are seven influencing conditions which are required for the formation of TIS building blocks (Ortt & Kamp, 2022):

1. **Knowledge and awareness of technology**: knowledge of the technological principles concerned with the product and operational processes along its lifecycle.
2. **Knowledge and awareness of application and market**: knowledge of potential applications for the product, the market structure in which the product competes, and the actors involved.
3. **Natural, human, and financial resources**: raw materials, knowledge, competencies, and monetary assets.
4. **Competition**: competition between products and subsequently between networks of companies due to differentiation in business model (within-product competition), product type (within-technology competition), and/or technology (within-industry competition).
5. **Macro-economic and strategic aspects**: economic and political background in which a product is introduced, reflected respectively in e.g. GDP and government policies.
6. **Socio-cultural aspects**: habits, norms, and values of a particular culture or socio-technical system.
7. **Accidents and events**: significant developments, either internal or external to the TIS.

If any of the seven building blocks are not present, this forms a barrier and hampers large-scale diffusion. This can be attributed to any combination of influencing conditions. Based on the status of the TIS building blocks and influencing conditions, a type, scale, and timing can be formulated for niche introduction strategies to overcome the barriers. An overview of the framework, taken from Ortt and Kamp (2022), is presented in Figure 3.1.

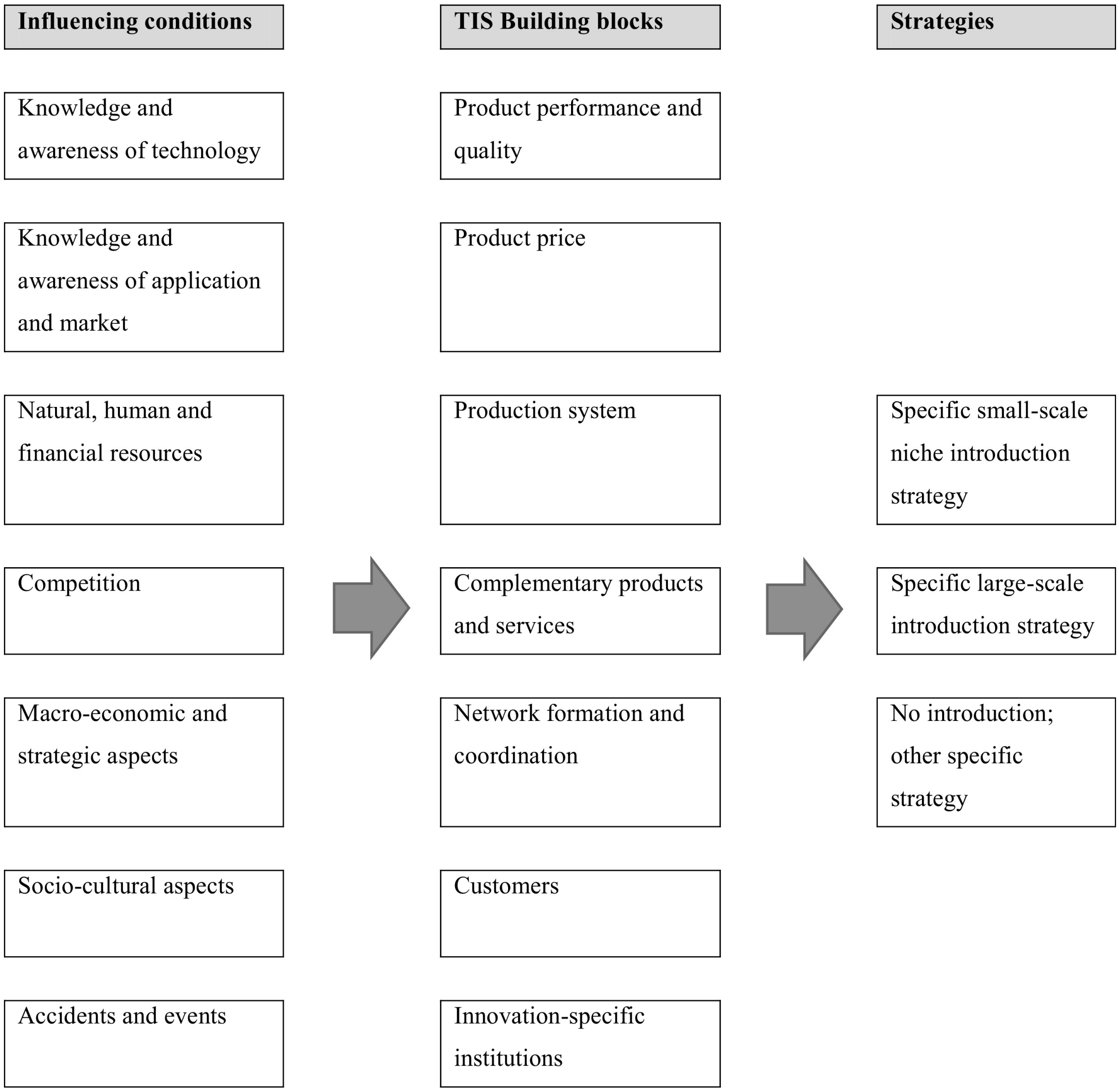


Figure 3.1: TIS framework, taken from Ortt and Kamp (2022)

The research diverged from the model of Ortt and Kamp (2022) in two aspects: 1) the perspective from which systemic barriers are managed and a strategy is formulated, and 2) the building blocks and influencing conditions that together formulated the TIS. These are summarized in Table 3.1.

Table 3.1: Deviations from TIS

Framework	TIS (Ortt & Kamp, 2022)	Thesis (Willigenburg, 2026)
Perspective	Company perspective	Multi-actor perspective
Blocks and Conditions	Original	Altered in accordance with Verdegeaal (2023)

First of all, a comprehensive strategy was proposed from an overarching, multi-actor perspective rather than a company perspective. This allowed governments, companies, policy makers, and other stakeholders to collectively manage the barriers for large-scale diffusion of high-blend SAF. To define a strategy for multiple actors, existing literature on stakeholder participation and collaboration previously mentioned in section 2.3 was conjoined with the TIS framework. Second of all, the TIS building blocks and influencing conditions are slightly altered to accommodate the aviation industry, as also elaborated on in the Master's thesis by Verdegaal (2023). The new TIS building blocks and influencing conditions are respectively shown in Table 3.2 and Table 3.3.

Table 3.2: Adapted TIS building blocks

Building block	TIS (Ortt & Kamp, 2022)	Thesis (Willigenburg, 2026)
1	Product performance and quality	Product performance and quality
2	Product price	Product price
3	Production system	Production system
4	Complementary products and services	Complementary infrastructure and services
5	Network formation and coordination	Nework formation and coordination
6	Customers	Customers
7	Innovation-specific institutions	Innovation-specific institutions and industry-wide regulations

Within TIS building blocks, a distinction is made between factors and actors. The factors shall be: product performance and quality (F1), product price (F2), production system (F3), complementary infrastructure and services (F4), and innovation-specific institutions and industry-wide regulations (F5). Meanwhile, actors concern the remaining two TIS building blocks, network formation and coordination (A1) and customers (A2).

Table 3.3: Adapted TIS influencing conditions

<table>
<tr><th>Influencing condition</th><th>TIS (Ortt & Kamp, 2022)</th><th>Influencing condition</th><th>Thesis (Willigenburg, 2026)</th></tr>
<tr><td>1</td><td>Knowledge and awareness of technology</td><td>1</td><td>Knowledge and awareness of technology</td></tr>
<tr><td>2</td><td>Knowledge and awareness of application and market</td><td>2</td><td>Knowledge and awareness of application and market</td></tr>
<tr><td rowspan="3">3</td><td rowspan="3">Natural, human, and financial resources</td><td>3</td><td>Natural resources</td></tr>
<tr><td>4</td><td>Human resources</td></tr>
<tr><td>5</td><td>Financial resources</td></tr>
<tr><td>4</td><td>Competition</td><td>6</td><td>Competition</td></tr>
<tr><td>5</td><td>Macro-economic and strategic aspects</td><td>7</td><td>Macro-economic and strategic aspects</td></tr>
<tr><td>6</td><td>Socio-cultural aspects</td><td>8</td><td>Socio-cultural aspects</td></tr>
<tr><td>7</td><td>Accidents and events</td><td>9</td><td>Accidents and events</td></tr>
</table>

3.2. Research approach

To systematically identify, categorise, and compare pathway-specific barriers across different stakeholder groups, the research was conducted using a qualitative approach. Figure 3.2 displays the research approach in more detail, which is further elaborated upon in the following subsections.

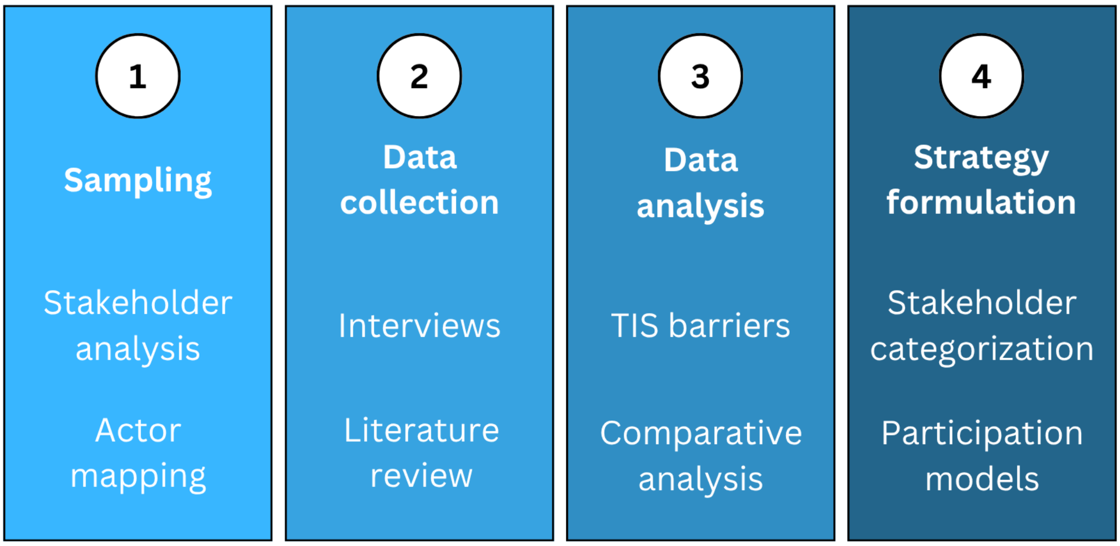


Figure 3.2: Approach used for the research

Sampling

To ensure that the studied sample was representative of a range of stakeholder groups involved in the implementation of SAF and an uptake in blending, a comprehensive stakeholder analysis of the SAF industry was performed in chapter 4, which placed stakeholders along the participation continuum. The position of each stakeholder group was determined based on their level of participation in the SAF ecosystem that is associated with each stakeholder group in its normal operational role. Based on this initial analysis, seven categories of stakeholders - the majority of which were located in the higher rungs of the participation continuum - were identified as the most relevant to this study: original equipment manufacturers (OEM), fuel suppliers (FS), airlines and airports (AIR), infrastructure (INF), institutions (INST), external experts (EX), and trade organisations (TRO). From each category, no more than three subjects were contacted to form a sample of 14 specialists in the alternative aviation fuel industry. The list of subjects is summarised in Table 3.4 below.

Table 3.4: List of interviewees, in chronological order of interviews

#	Date	Stakeholder category	Interview ID
1	27-03	External experts	EX-1
2	01-04	Airlines and airports	AIR-1
3	01-04	Institutions	INST-1
4	10-04	External experts	EX-2
5	15-04	External experts	EX-3
6	20-04	Equipment manufacturers	OEM-1
7	20-04	Institutions	INST-2
8	21-04	Trade organisations	TRO-1
9	05-05	Fuel suppliers	FS-1
10	07-05	Fuel suppliers	FS-2
11	08-05	Infrastructure	INF-1
12	08-05	Fuel supplier	FS-3
13	08-05	Equipment manufacturers	OEM-2
14	22-05	Airlines and airports	AIR-2

Data collection

The qualitative analysis was performed using semi-structured interviews. This helped cover specific topics, but also allowed for enough flexibility during the interview to adapt to responses given by the interviewee and gain an augmented understanding of specific insights. A loose transcript was prepared in advance of the interviews, after which the interviews were recorded and transcribed in Teams. Transcriptions were edited and sent to the participants within two weeks of the interview date, who were then able to suggest any modifications if desired within the next two weeks.

Data analysis

Transcribed data from the interviews was coded in Atlas.TI. For the initial analysis, a middle-ground approach was used. A longlist of codes was initially deduced from findings from the literature review in chapter 2, but evolved during the analysis as new codes were added to the list or old codes were replaced, as noted in Appendix D. Three analyses were performed in parallel: barrier analysis, comparative analysis between synthetic blending components (SBCs), and formulation of measures.

For barrier analysis, the central phenomena (core categories) around which the codes are interrelated were already determined in advance, namely, the modified seven building blocks and nine influencing conditions (ICs) from the TIS framework specified in section 3.1. Questions 3, 5, 6, and 7 in the interview protocol were designed to prompt the responses used to generate a longlist of codes, of which each code was then grouped under either one of seven TIS building blocks or nine ICs. Ultimately, two thematic maps were created which visualised the coupling of each code to its respective core category.

For the comparative SBC analysis, all known SBCs under American Society for Testing and Materials (ASTM) standard D7566 or in development were marked and tallied in textual data, with question 4 of the interview protocol specifically designed to prompt responses relevant to this topic. Based on this, the most relevant SBCs were investigated. Thereafter, pathway-specific barriers were identified, and SBCs were compared across these barriers.

For the formulation of measures, question 8 of the interview protocol was designed to prompt responses relevant to the topic. As opposed to the barrier and SBC analysis, however, core categories were not determined in advance. This list of overarching measures - the core categories - was instead loosely induced from textual data. Then, provided a list of key challenges taken from the barrier analysis, each measure type was linked to a challenge based on interview responses. The link between challenge and measure was further verified using the ICs identified for each challenge. Provided questions 9 and 10 in the interview protocol, the relevant actors to undertake each measure were also identified to map stakeholders along the participation continuum for each TIS (f)actor. Here, the participation continuum was modified to only include the top five rungs, because key stakeholders were assumed to take on a minimum level of participation.

4 Stakeholder Analysis

This chapter aims to answer RQ1, identifying and assessing stakeholders who are involved in the transition toward higher sustainable aviation fuel (SAF) blend ratios to gain more insight into the SAF industry. First, an exhaustive analysis of all stakeholders is provided in section 4.1 to gain a better understanding of how much every stakeholder participates in the SAF ecosystem. Based on this analysis, the key stakeholders are then identified, who shall be interviewed in subsequent analyses. These key stakeholders and their connectedness are also further explored in an actor map in section 4.2.

4.1. Analysis of stakeholder participation in the SAF ecosystem

A technological transition from conventional aviation fuels (CAF) to higher blend ratios of SAF does not only involve technological changes, but also affects other dimensions such as regulations, industrial networks, and infrastructure (Geels, 2002). These dimensions are represented by stakeholders: those who hold a stake in the problem because they are affected by its outcome. As evident from research by Carrera et al. (2021) and Luyet et al. (2012), a stakeholder analysis needs to be performed to guide stakeholder collaboration. Figure 4.1 illustrates the mapping of all stakeholders in the SAF ecosystem along a stakeholder participation continuum. Here, stakeholders are categorized based on their level of participation in the SAF ecosystem, respectively ranging from ignorance to empowerment. In doing so, key stakeholders can be identified.

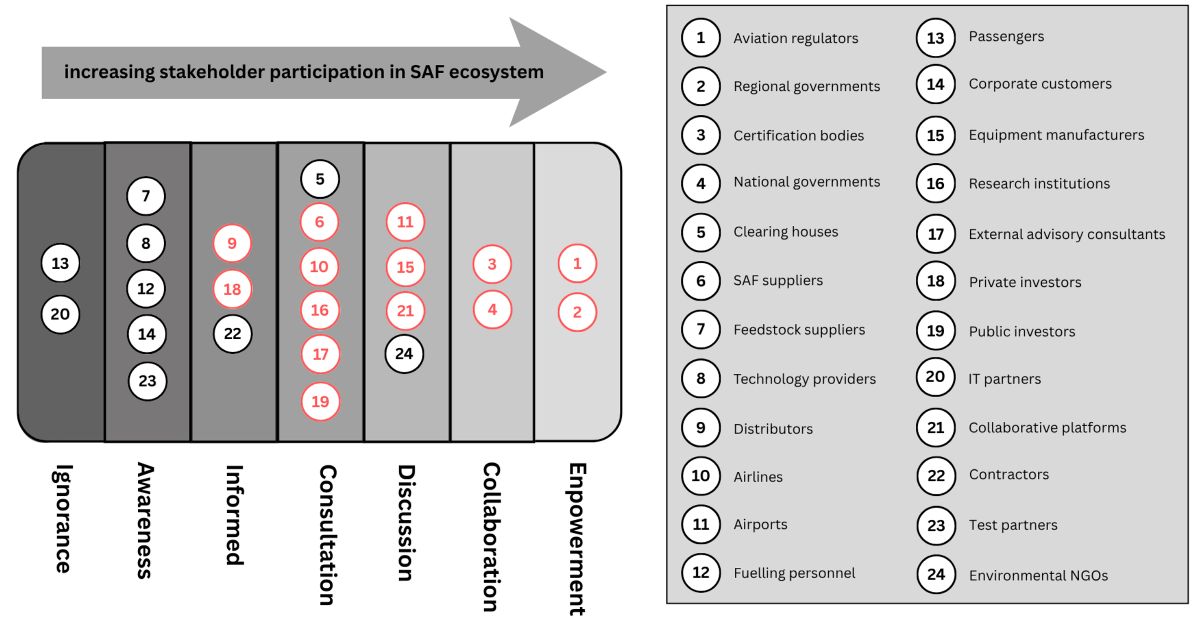


Figure 4.1: Categorization of stakeholders along the participation continuum, adapted from Carrera et al. (2021) and Bammer (2019); key stakeholders denoted in red

Although many of the metrics along the axis are very similar to the IAP2 spectrum of public participation used by Bammer (2019), they elaborate how this can be adapted for research purposes such as the analysis of participation for all stakeholders within an ecosystem. Meanwhile, Carrera et al. (2021)'s involvement model utilizes a ladder of participation along its y-axis to distinguish between different levels of stakeholder involvement. The model in Figure 4.1 is a synthesis of both models, which takes Bammer (2019)'s model as a basis and extends it with lower rungs taken from Carrera et al. (2021), i.e., "ignorance" and "awareness". Furthermore, "involvement" is renamed to "discussion". The revised rungs of participation are defined in Figure 4.2 below, with key stakeholders denoted in red.

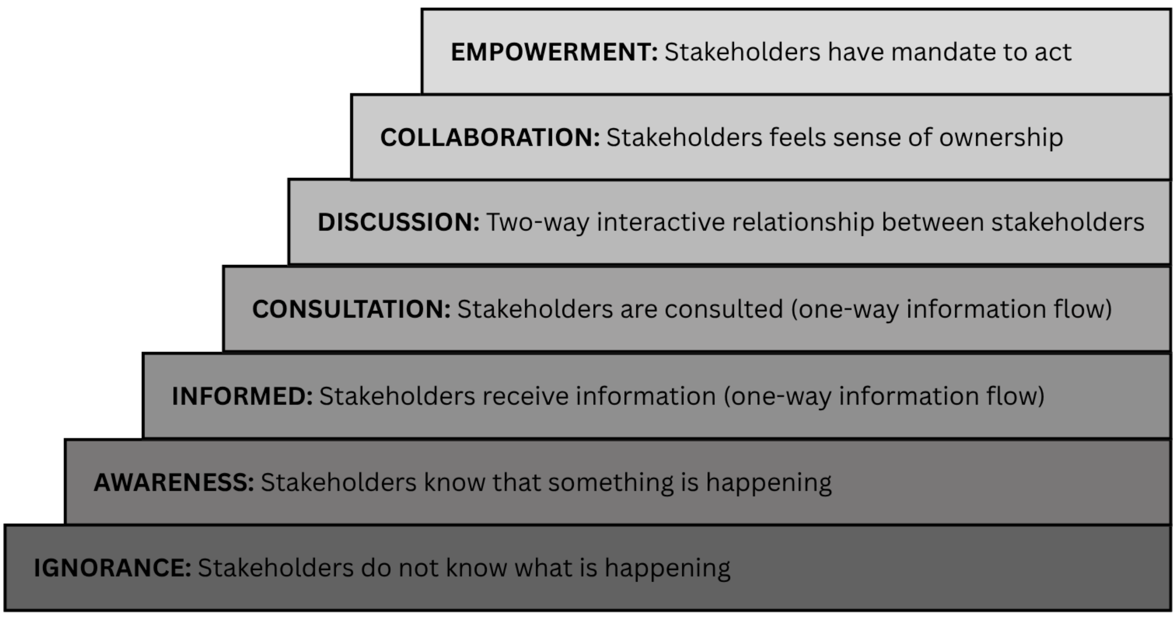


Figure 4.2: Definitions of ladder of participation, taken from Carrera et al. (2021) and adapted to the metrics used in Figure 4.1

The rungs of the participation ladder and the placement of stakeholders in each rung are further elaborated upon below. The first rung along the participation continuum, as shown in Figure 4.2, is labelled ”ignorance”. Stakeholders placed inside this rung do not know what developments are happening inside the SAF ecosystem. As shown in Figure 4.1, passengers (13) and IT partners (20) are placed here because they perform their ”function” independently from any other stakeholders with very limited involvement in or influence on the SAF ecosystem. The second rung is labelled ”awareness”. Stakeholders are aware of ecosystem developments, but still hold limited involvement. Stakeholders placed here are feedstock suppliers (7), technology providers (8), fuelling personnel (12), corporate customers (14), and test partners (23). Corporate customers (14) are notably placed higher than passengers (13), because they are deemed more informed in SAF uptake. The third rung is labelled ”informed”, reserved for distributors (9), private investors (18), and contractors (22). The distinction between ”informed” stakeholders and ”aware” stakeholders is that informed stakeholders actively seek to be informed by other stakeholders in a one-way flow of information, because they are more essential to internal processes and are therefore assumed to hold a higher interest in ecosystem developments. The fourth rung, ”consultation”, further illustrates the value that stakeholders add to the ecosystem, consulted by others because of the knowledge and capabilities they possess. Stakeholders placed here are SAF clearing houses (5), SAF suppliers (6), airlines (10), research institutions and external advisory consultants (16, 17), and public investors (19). As opposed to private investors (18), public investors (19) are placed in a higher rung because they are more closely related to authoritative bodies. Next, the fifth rung is labelled ”discussion”. Whereas the third and fourth rung acted as a one-way flow of information, stakeholders in this rung engage in an interactive, two-way flow of information. Airports (11), equipment manufacturers (15), collaborative platforms, and environmental NGOs (24) are placed here because of their specific power and/or influence. Airports (11) are notably placed in a higher rung than airlines (10), because they operate in a higher level of hierarchy in the aviation industry. This is also argued for equipment manufacturers (15) as opposed to SAF suppliers (6), because players in this market are fewer in number. The sixth rung is labelled ”collaboration”. Placed here are certification bodies (3) and national governments (4), who are similarly essential to the operation of the SAF ecosystem as stakeholders in lower rungs but yield more authority and are denoted to feel a sense of ownership. This also holds for the seventh and final rung, ”empowerment”, reserved for aviation regulators (1) and regional governments (2) who have a mandate to act. These authoritative bodies are, however, placed in a higher rung because their legislation can be more strictly enforced for a wider scope of the ecosystem.

A minor caveat to the involvement model above is that it is not meant to assign fixed positions to stakeholders. The positions shown in Figure 4.1 represent a snapshot of the SAF ecosystem and reflect the forms of participation that are associated with each stakeholder group in its normal operational role. Stakeholders, however, may occupy different positions depending on the context. For example, SAF suppliers (6) and airlines (10) may normally make independent operational decisions while remaining highly informed about developments in the SAF ecosystem. In a collaborative initiative, however, these actors may move towards higher levels of participation, such as discussion, collaboration, or even empowerment. Thus, the position of stakeholders in the model should not be interpreted as indicators of their importance, influence, or power, but rather as representations of how stakeholders are typically engaged in the ecosystem.

Furthermore, it should be noted that while these stakeholders can be generalised for any local ecosystem of stakeholders, this research focuses on the SAF industry in the European Union (EU) region due to the limited research time available. This assumes that interregional policy-making does not affect the development of a strategy. Furthermore, although the number of stakeholders extends far beyond the sample group as noted in section 3.2, the scope of this research shall be limited to the key stakeholders denoted in red. This is because these stakeholders are determined as key stakeholders who actively participate, influence, or interact with the development of the SAF industry and are therefore the most relevant stakeholders to this study. For a more detailed description and specification of these stakeholders, reference is made to Appendix B.

4.2. Detailed overview of key stakeholders

Based on the multi-actor network presented by Geels (2002), an actor map is presented in Figure 4.3 to show a more detailed overview of different actors inside each of the key stakeholder groups alongside their connectedness.

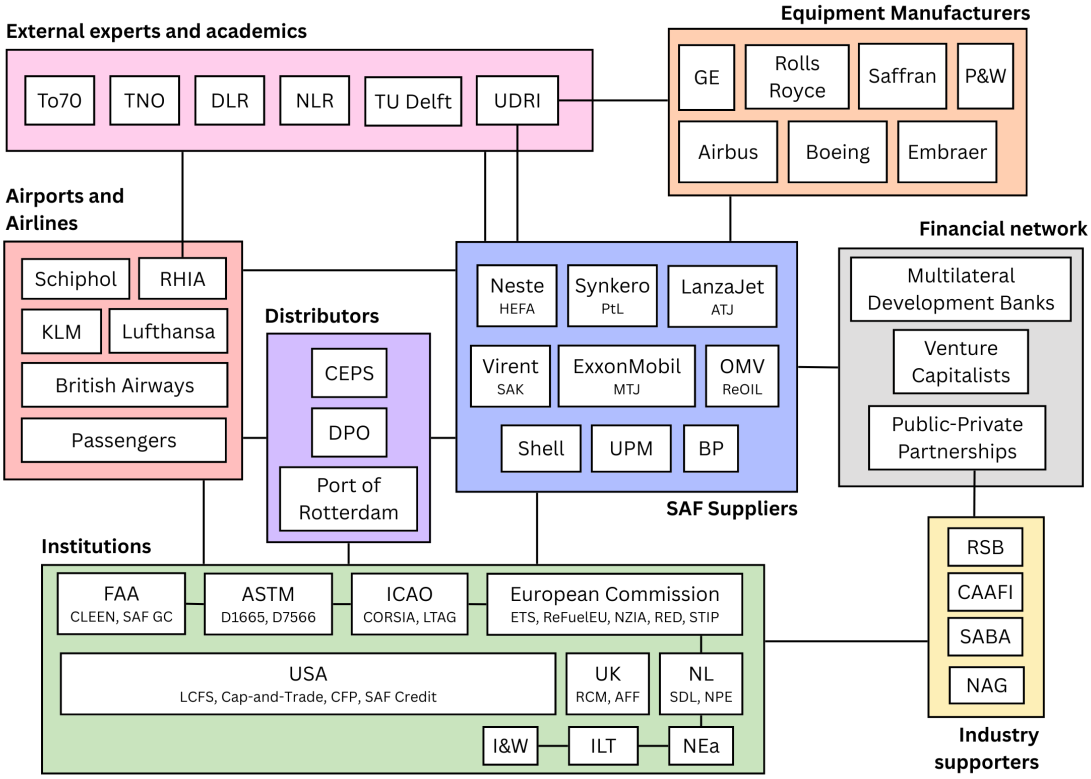


Figure 4.3: Actor map of international SAF development efforts

In Figure 4.3 above, individual actors are placed in one of the following categories: (1) external experts and academics; (2) equipment manufacturers; (3) airports and airlines; (4) distributors; (5) SAF suppliers; (6) financial network; (7) institutions; and (8) collaborative platforms. The eight primary groups and examples of actors within each group are identified based on the results presented in Appendix B.

5 Barrier Analysis

In previous chapters, a background on sustainable aviation fuels (SAF), the Technological Innovation System (TIS) framework, and key stakeholders who are involved in the technological transition toward higher SAF blend ratios has been established. The following chapter builds on this background information and aims to answer the first half of RQ2, identifying which types of barriers currently prevent SAF blending beyond 50%. In order to do so, the state of the innovation is placed in the TIS framework through a discussion of interview findings. Here, the innovation (or rather, the product) shall be formally defined as **SAF with blend ratios above 50%**. In Figure 5.1, a thematic network presents a global overview of all identified codes grouped under one of seven TIS building blocks from Table 3.2. Each colour in the figure represents a (f)actor of the system, for example, *F1 - Product performance and quality*. Below each of these factors are smaller blocks. These are codes identified from the analysis of textual data from the 14 conducted interviews, which are subsequently linked to the relevant (f)actor. For example, the codes identified from textual data that were grouped under F1 are *feedstock variability*, *production uncertainty*, and *system compatibility*. To add to this, a second overview presented in Figure 5.2 illustrates all nine influencing conditions (IC) previously mentioned in Table 3.3 and the codes linked to them. In most cases, a TIS (f)actor code linked to an influencing condition has a direct connection to one of the codes grouped under the relevant influencing condition, because it is mentioned in the same text or around it.

In the following sections, each of the seven TIS building blocks is discussed in its respective section. The chapter concludes with a summary in section 5.8 which presents the current status of all TIS building blocks and influencing conditions.

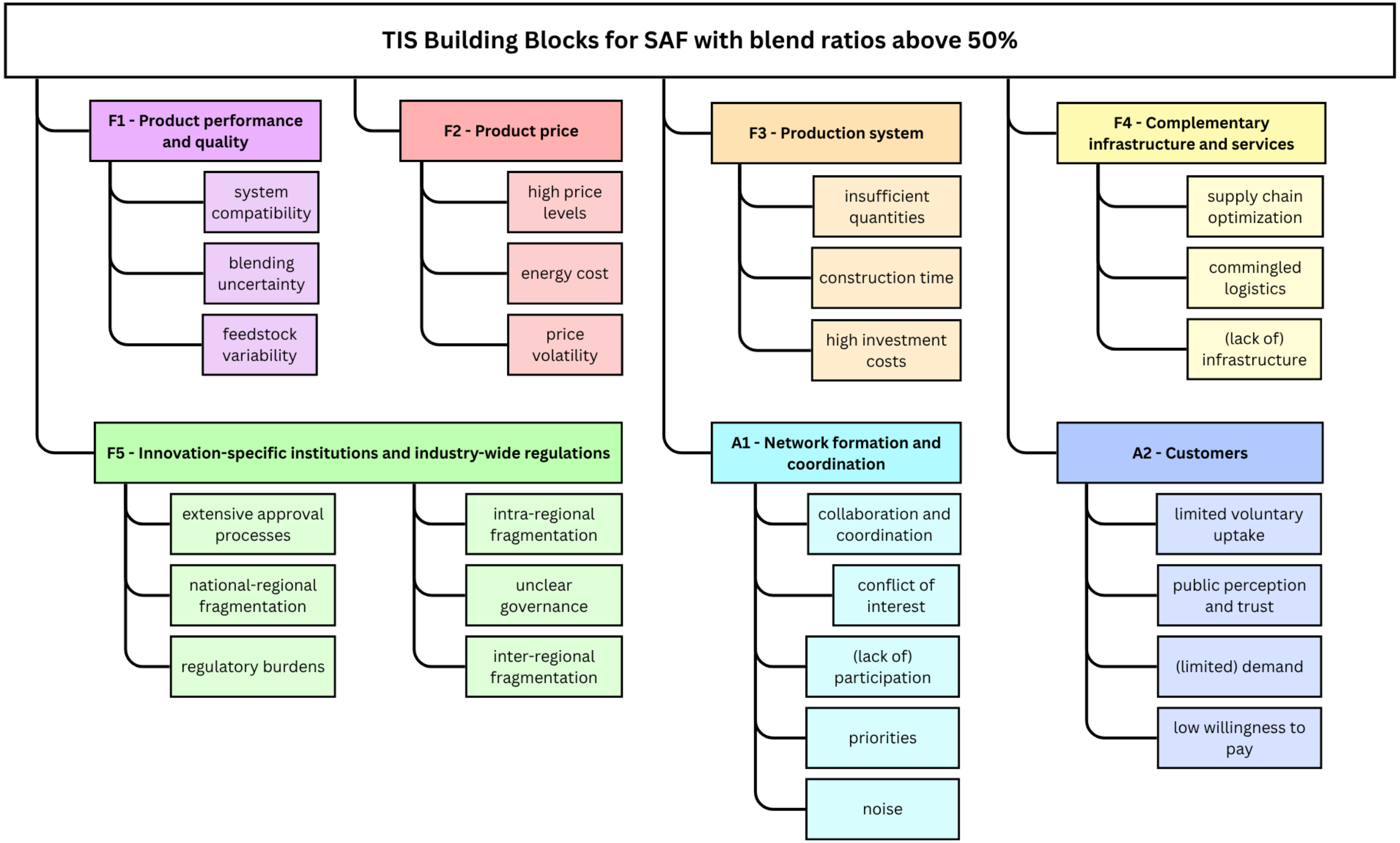


Figure 5.1: Overview of codes grouped under each TIS building block

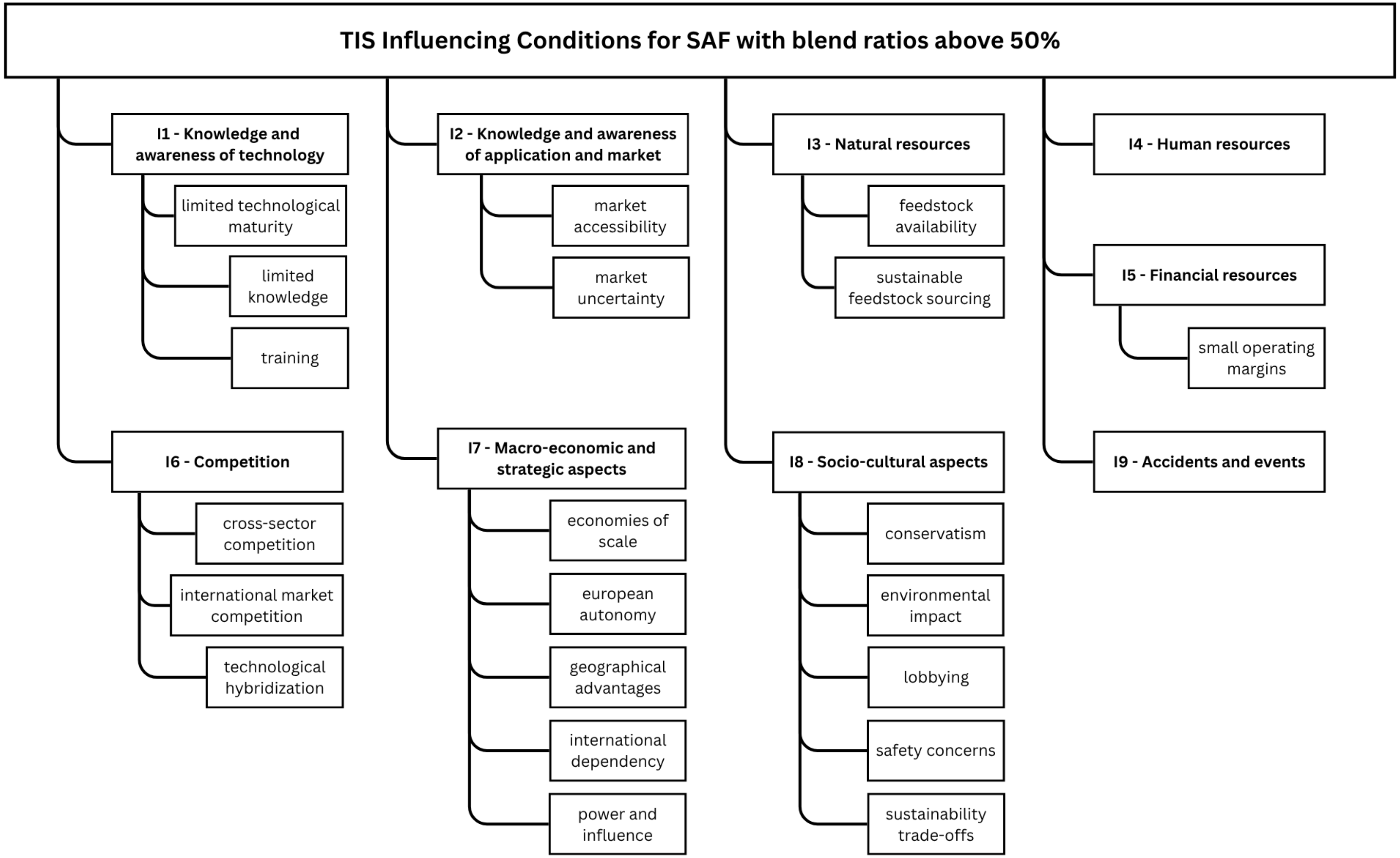


Figure 5.2: Overview of codes grouped under each TIS influencing condition

5.1. Product performance and quality (F1)

In this section, the product is investigated concerning performance and quality relative to competitive products. For this factor, three descriptive codes have been identified: ”system compatibility”, ”blending uncertainty”, and ”feedstock variability”. Table 5.1 visualises the rate of occurrence of each code throughout the dataset. It should be noted that the rate of occurrence does not represent the significance of one code over another, but rather serves as a means of visualising how some topics receive more attention from participants, or are more widely known among them.

Table 5.1: Rate of occurrence of codes under F1 (product performance and quality)

	Interview														
Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Sum**
system compatibility	5			3	3	3			1	3		3	2		23
blending uncertainty	4			2			2					1			9
feedstock variability	2					1									3

5.1.1. System compatibility

Influencing conditions: IC1, IC5, IC7, IC8

The first code to discuss is ”system compatibility”, which refers to the compatibility of the product with the rest of the environment it is used in. The term ”system” is used here to acknowledge that, in the case that high-blend SAF will be adopted, it requires changes to multiple elements in the aviation ecosystem. This is also elaborated upon by OEM-1 and OEM-2 in the following quotes:

> **OEM-1:** *”It’s true that you have to look at the fuel system and the engines. Are they compatible with this [**fully paraffinic fuel**]? [...] At aircraft level, we can do it. [...] You have to look at the **global ecosystem**. And in the global ecosystem, it’s about distribution of such a fuel. You introduce your new fuel grade. Now, you see when you go to the airport, the tanks with Jet A-1 on it, it means you need to build new tanks or to repurpose existing tanks. You need to have segregated supply. You need to make sure you will not mix it. And when you look at this, it has some **cost**.”*

> **OEM-2:** *”HEFA-SPK, sure, from an availability perspective, it is currently a little bit more attractive, but it has tremendous challenges. [...] It’s not just the fleet, but also the **infrastructure** needs to be **compatible**. We’re talking about pipelines, trucks, rail cars, barges, airport equipment such as filtration equipment, and you name it, they all need to be compatible with an **aromatic-free fuel**. [...] What that means is a paraffinic-only option would require a separate segregated infrastructure for that grade.”*

As OEM-1 and OEM-2 point out, introducing a new fuel grade requires changes to the entire ecosystem, which will be accompanied by high costs. Therefore, when a synthetic blending component (SBC) is blended with Jet A-1 fuel, which typically contains 15 to 20% aromatics, no more than 50% of an aromatic-free SBC can be used in the blend to adhere to the aromatics requirement and be used in the existing ecosystem. In other cases, this extends beyond the aromatic content to other performance properties such as density or freezing point. However, because SAF is a relatively new product compared to Jet A-1, there is a degree of uncertainty due to a lack of knowledge (IC1) to what extent aircraft need to comply with these performance properties, and whether such constraints could be further relaxed. This uncertainty is illustrated by statements from FS-1 and OEM-1 below.

> **FS-1:** *"I would say that it should be then investigated to what level the minimum aromatics could be decreased to keep these operations very efficient and so on. [...] It should also be investigated if min. 8% aromatics is really required, or could it be something lower, like 4% or 2%, or what could it be? The industry should seek for [a] variety of options and flexibility to enable higher SAF content in the future."*

> **OEM-1:** *"I think it is really about mastering all these **fit-for-purpose properties** that I mentioned earlier, [...] how with only a few controls on specification you can ensure that these controls are sufficient to ensure the OEMs will meet the specification, you will remain in the safe in your experience, where your engines, everything is certified. So, this demonstration that we are actually drop-in beyond 50%."*

Provided this context, an aromatic-free or low-aromatic fuel as referenced by OEM-1 and OEM-2 - equivalent to a higher blend ratio - is not yet feasible under current regulations. In light of the discussion for decreased aromatics, however, the Jet X specification is being developed for future aircraft to act as a separate standard to which SAF can conform. By developing such a specification and advocating for zero-aromatic fuels, future fuels would become considerably cleaner as aromatics are noted to be a major component of local pollution and non-carbon dioxide (CO_2) emissions. With sustainability becoming a more frequent topic in society, this environmental factor is also taken into consideration when discussing aromatics (IC8). However, as explained earlier, the Jet X specification would also require changes to the existing ecosystem of actors and its practices - an ecosystem which spans internationally - which makes it a significant hurdle to overcome due to the required investments in an international market (IC5, IC7).

5.1.2. Blending uncertainty

Influencing condition: IC1

> **EX-2**: *"In practice, what we often see is blend ratios around 30%. I've recently also heard more like 40%, but we really don't go too close to 50% because if we go **off-spec**, then well, we have to re-blend which is more costly and all that. And when we blend, there are properties that **do not blend linearly**. So it's not like you cannot look at the two fuels and then think that the blend is going to be in the middle for every property. Because some properties, you cannot really predict how it's going to react between two fuels. So that's why you always have to aim for a bit lower blend ratio."*

In this second section, the code "production uncertainty" is discussed. As suggested by EX-2, fuel producers tend to stay substantially under the blending limit of 50%, because producers must account for non-linear blending between Jet A-1 and SBCs. In other words, because producers cannot adequately control and predict the properties of the final SAF product, they remain at least 10 to 20% under the blending limit to prevent producing an "off-spec" batch that does not adhere to the regulated specifications and results in financial losses. This is effectively the result of limited knowledge (IC1) regarding the optimization of production processes with respect to mitigating uncertainties due to non-linear blending properties.

5.1.3. Feedstock variability

Influencing condition: IC1

> **EX-1**: *"Because there's nothing worse for a fuel producer than an **off-spec** batch, which would lead to a lot of costs, the majority of fuel producers currently will generally blend at around 37% or 38%. If they go above that, there's a very small chance when they do the final test that it's off spec."*

> **OEM-1**: *"So indeed, being able to push the limit from 30% to 50% will help, it helps the logistics in the end. [...] But today, there is much more* ***viability*** *on the 1st order due to the* ***variability*** *of the UCO or the feedstock cost compared to the logistic optimization that you would get from going from 30%, 35% to higher blend ratio."*

In this third and final section, the code "feedstock variability" is discussed. As noted by EX-1, another reason why SAF producers tend to stay under the blending limit of 50% is due to variability in the feedstocks used, with the production method accounting for a larger uncertainty for more complicated processes while variability in feedstocks used holds more significance for simpler processes. As OEM-1 states, this is significant for the 1st-order cost of the SAF produced. In a similar vein to "production uncertainty", because producers cannot adequately control the feedstock variability, they remain at least 10 to 20% under the blending limit to prevent producing an "off-spec" batch as a result of limited knowledge (IC1).

5.2. Product price (F2)

Product price pertains to a product with sufficient price levels relative to competitive products. Thus, all cost and price-related codes are discussed here. These are: "high price levels", "energy cost", and "price volatility", the rate of occurrence of which is shown in Table 5.2.

Table 5.2: Rate of occurrence of codes under F2 (product price)

	Interview														
Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Sum**
high price levels	1	3	4	5	2		1		1	2	1		2	4	34
energy cost	1		2		2			4							9
price volatility			3		1									3	7

5.2.1. High price levels

Influencing conditions: IC1, IC5

To introduce the current situation of SAF's price levels, this section begins with an analogy used by EX-2.

> **EX-2:** *"I mean, fuel is a bit like wine. We often take this comparison because there are different ways of producing fuel and you can also improve the quality, but then it costs more, right? Like, it's more energy, the process is longer, and requires more steps to make a better jet fuel, a better product. And in the end, we want to keep the cost low, so* ***it's a bit of a trade-off between having a good, clean fuel [...] and keeping a cheap fuel.****"*

> **FS-2:** *"If you look at the costs of an airline, then about 1/3 of that is linked to fuel. A lot fuel goes into an aircraft - I'm sure you're aware - and that fuel is not free. [...] And if you look at SAF, it is simply at least* ***twice as expensive****. Yeah, that won't work. They* ***simply cannot afford that****, unless the ticket prices increase twofold. But yeah, then they won't have a competitive position anymore, so that won't work."*

> **AIR-1:** *I think it is especially* ***commercially difficult****. The margins in the aviation are not that large, so I think the full focus of airlines lies with cost reduction. And if there is something that does not contribute to cost reduction, it's SAF.*

SAF is widely acknowledged among all interviewees to be more expensive to produce than Jet A-1, with its cost at least two to three times as large. This is because feedstocks, as previously mentioned by EX-2, go through a more rigorous process of being harvested, sorted, cleaned, and converted into fuel.

Statements by FS-2 and AIR-1 further illustrate another significant hurdle to why a price gap cannot be easily bridged: not only is SAF more expensive than competitive products, the end-users are also active in an industry which operates under very small margins (IC5). Therefore, airlines are unlikely to cover the price gap or consume more SAF than the mandated minimum. Furthermore, because these pathways still lack maturity and cost optimization with respect to hydro-processed esters and fatty acids (HEFA) (IC1), the industry still relies heavily on HEFA-SAF until its feedstocks are fully depleted. This, in essence, captures the first-order lever of SAF production costs as noted by EX-1 in the statement below.

> **EX-1:** *"The main drivers for SAF production are feedstock availability and [production] cost. [...] They care about how they can make it as cheap as possible and how they can get as much feedstock as possible."*

5.2.2. Energy cost

Influencing conditions: IC3, IC6, IC7

> **TRO-1:** *"It takes a large amount of energy to make e-SAF. And if you want it to be competitive to the cost of Jet A-1, then you're going to have to lower your **energy cost**. We spoke to another organisation that works with us [...] and the director of that organisation said, 'I know one of the bigger things that we want is, we want cheaper electricity so that when these larger companies start producing e-SAFs, that they can be closer to competing with traditional fuels'. So that is another huge hurdle. The Netherlands is **not exactly cheap** when it comes to energy cost."*

Secondly, as TRO-1 explains, a significant step in lowering SAF production costs can be derived from lower electricity costs, especially for e-SAF. This is because the steps used for processing feedstocks are inherently energy-intensive processes. In areas where little electricity is available, the price of electricity rises (IC3). This may result from net congestion in countries like the Netherlands (IC7), but can also be a direct consequence of cross-sector competition (IC6), as evident from the statement by EX-2 below.

> **EX-2:** *"There was a project for power to liquids production in Iceland and they had secured renewable electricity. And in the end, the company with all the renewable electricity decided not to go provide renewable electricity for the SAF plant, but there was a demand for a data centre and they said, 'well, for sure, data centre, they need electricity, so they will be ready to pay whatever amount. So we'll provide all the electricity to a data centre.' We are not alone and **it's not only competition between aviation and maritime or aviation and road transport**."*

5.2.3. Price volatility

Influencing conditions: IC2, IC9

A third topic that is discussed separately from the price levels is the *rate* at which the price levels fluctuate, labelled in the code as "price volatility". To introduce this concept, some statements from INST-1 and EX-3 are given.

> **INST-1:** *"The problem is not necessarily just in the absolute price difference - which definitely is a factor [...] - but also in the **risks**. The price developments are **uncertain**. We are not sure how the price will develop and if it will significantly decrease or remain multiple times as high as fossil [fuel]. So that also makes it difficult - we see that really well in the sector - to, for example, sign an off-take agreement between producers and consumers."*

> **EX-3:** *"I think what they're also doing in the UK, they have a regulation there for price insurance. [...] I think such an agreement would help a lot, because with fluctuating prices, airlines are hedging their fuel. [...] If you don't know what the price is going to do because the developments are uncertain, then it is* ***very difficult to commit*** *to an off-take [agreement]. You don't know if it is beneficial or not."*

The aviation sector is a price-sensitive sector with limited operating margins. As noted by INST-1 and EX-3, it therefore becomes increasingly difficult to sign an off-take agreement and further stimulate the supply and demand of SAF when price levels are unstable because of market uncertainty (IC2). Because off-take agreements are commonly indexed on Jet A-1 prices as noted by AIR-2, events that impact either the alternative or the conventional fuel industry may have lasting ripple effects on the price level of SAF (IC9). Examples of such events that were mentioned in interviews are the closing of Shell's and BP's SAF factory in Rotterdam (INST-1, EX-3, INST-2, TRO-1, FS-2, FS-3) and the closing of the Strait of Hormuz due to the war in Iran (EX-3, INST-2).

5.3. Production system (F3)

To enable large-scale adoption of the product, the production system must be able to produce sufficient quantities relative to competitive products. To analyse these barriers, three codes have been formulated which shall all be discussed in this section: "insufficient quantities", "construction time", and "high investment costs".

Table 5.3: Rate of occurrence of codes under F3 (production system)

	Interview														
Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Sum**
insufficient quantities	4	3		2	4	1	1	1	1	4	1	2	1	3	28
construction time			1							1		2	1		5
high investment costs			1							1			1		3

5.3.1. Insufficient quantities

Influencing conditions: N/A

The first and arguably most critical code to discuss here is the code labelled "insufficient quantities". When interviewees were asked to what extent the current SAF blend limit of 50% formed a constraint, the most common response pertained to the current SAF production volume, as explained by EX-1 and EX-3.

> **EX-1:** *"The fuel spec for many SAF producers is currently not an issue because we have* ***insufficient SAF*** *to get anywhere above a high percentage of blends. So, because we only have about 2.7% now in Europe of fuel with SAF, you've got such a broad range of blending. You can always get to the 20%, 30%, and still have enough room to play with that the fuel producers don't focus on this."*

> **EX-3:** *"That's not necessarily a constraint because we cannot meet it because there is simply* ***very little SBC available****. But it will be a problem on the* ***long term****, definitely for for example ReFuelEU that wants to go to 70% blending."*

> **FS-2:** *"You mustn't forget that the SAF volumes are actually* ***really limited*** *globally. We're talking about a few percent on global scale compared to the rest of the fossil fuels, so the 50% is actually not really a factor at this moment."*

The ReFuelEU aviation mandate, which broadly reflects the industry's current SAF capacities, currently requires all fuel producers to blend SAF with Jet A-1 at 2%, which will not increase until 2030. Following

EX-1's and FS-2's logic, because mandated percentages are so low, fuel producers are not interested in blending at percentages near the blending limit because SBC supply is still very limited.

However, as EX-3 points out, the blend wall will become a problem in the future when mandated percentages increase to e.g. 6% in 2030 or 20% in 2035. In other words, the blend wall is not a problem of today, but should be surpassed to prepare the industry for tomorrow. That being said, the blend wall has a lower priority compared to driving the general uptake of SAF to meet the mandated percentages described by ReFuelEU aviation. To then shift the perspective towards the general uptake of SAF, interviewees share similar concerns about whether sufficient quantities are being produced.

> **OEM-1:** *"50% plus is the future, but the present and the near future is really to **kickstart this production**."*

> **TRO-1:** *"So right now, if we take a look at the production in Europe, [...] even if you were to take all the flights that come in under Schiphol and you mix them 2%, our supply of SAF is **not enough** to handle that for a full year. So even if we do all flights from Schiphol 2% mixing, **we don't have enough supply** to do it for a full year. And that is a big problem, a supply chain issue."*

> **EX-3:** *"And I think that the biggest argument becomes to shift from that current 2% to 3% to what it has to be in 2030, 6%, that it becomes an issue of **availability** and **scaling up production capacity**."*

> **FS-2:** *"And the funny thing is, at the moment this [limited supply of SAF] is not the case. At the moment we are actually in an **oversupply** market. Recently, there has been an increase in production capacity, especially in Asia and China. So at the moment we are okay. However, we expect that the mandate will grow faster than new plants will be built. So eventually, around 2030, we no longer expect an oversupply, but an **undersupply** market."*

In all statements, concerns are voiced with respect to the upscaling of SAF production to meet future mandated blending percentages. FS-2 proceeds to explain that, while there is enough quantity produced now, mandates will ramp up more rapidly than what the industry can keep up with. This especially holds for the production of e-SAF, which will require a 1.2% share by 2030, as evident from the following statements by INST-1 and INST-2.

> **INST-1:** *"It is really important that the development of advanced bio-fuels is seriously looked at. You can see a lot of movement around e-SAF at the moment. That's logical, because there will be mandates in 4 years which the sector must meet and there is **not a single large e-SAF factory in Europe**, so that is a worry. I'm not exactly worried, but I definitely see challenges to scale up the advanced bio-fuels on time and make that technology ready."*

> **INST-2:** *"That [e-SAF] is **not ready in the slightest**. We need 1.2% [...], but I don't think we're going to make it. That will definitely become a problem. Then the kerosene becomes significantly more expensive. There will be a lot of demand [for e-SAF], but there is **too little hydrogen** to make it."*

5.3.2. Construction time

Influencing conditions: IC1

To further proceed with the discussion of SAF production capacity not scaling up fast enough, FS-3 also shares his concerns regarding e-SAF. This, however, also sheds some light on the second identified code that falls under the formation of the production system, namely, "construction time".

> **FS-3:** *"Well, e-SAF is a **whole new technology**. It's the next generation of molecules. [...] To build such a plant, you'll be busy for 3, 4 years. And if you've then built such a plant - so you're not just building a facility of two billion, flicking a switch, and e-SAF comes out on the other side - no, you're also busy for 2 or 3 years with commissioning. So to be producing e-SAF molecules at all between 2030 and 2035, that will be a **challenge**, let alone produce enough for what is needed. And then you also have your e-SAF trajectory, that will increase from 2030, 2031 with some flexibility, but the ramp-up will be **really fast**."*

As illustrated by FS-3, e-SAF production is approximately necessitated by 2030, but no production plants have yet been constructed to meet this goal. It takes 3 to 4 years to build such a plant, and then another 2 or 3 years for commissioning. In some cases, construction of a project is delayed to such an extent that it results in complete cancellation. An example of this is the closing of Shell's factory in Rotterdam as noted by FS-3 below as a result of technological challenges that were unaccounted for (IC1).

> **FS-3:** *"The **competitiveness** of such a facility has to do with what something costs to build. [...] And the longer it takes to build something, the higher the costs will ultimately be. **So eventually, if such a facility delays enough, it shoots itself in the foot.** And that delay [...] has to do with technological challenges, because such a facility, especially on such a scale, is still a first-of-a-kind."*

5.3.3. High investment costs

Influencing conditions: N/A

As previously noted, a SAF plant requires a lot of investment ("two billion" according to FS-3), which needs to be financed through a combination of government funding and private funding, respectively represented by government bodies and private investors. And to attract such a large amount of funding, these actors need to be convinced. This is further backed by OEM-2's statement:

> **OEM-2:** *"The cost of putting SAF facilities on the ground to begin with is a **big challenge**. That commercialization, going from a pilot plant scale to a commercial plant scale, suddenly you're talking about costs like $100 million. You need to convince investors or government help to basically finance those commercial facilities. So, that's definitely a **big challenge** as well."*

5.4. Complementary infrastructure and services (F4)

When discussing the complementary infrastructure and services of a product in aviation such as high-blend SAF, this is defined as the operations which add value to the supply chain of SAF outside of production and consumption. Codes that have been identified under this topic are "supply chain optimization", "commingled logistics", and "lack of infrastructure".

Table 5.4: Rate of occurrence of codes under F4 (complementary infrastructure and services)

	Interview														
Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Sum**
supply chain optimization	2	4	1	1	3	1			2	2	3	1	1	2	23
commingled logistics	5	1			2					1	3				12
lack of infrastructure				1	1	1					1				4

5.4.1. Supply chain optimization

Influencing conditions: N/A

First and foremost, actors in the SAF industry are currently focused on "supply chain optimization", which focuses on optimizing existing logistical processes rather than creating new processes. This is further discussed by EX-1 and FS-1 below.

> **EX-1:** *"I think in the next 10 years, fuel producers together with their blending partners [...],* ***they are going to stay within 30%****. They have no incentive to go above that. They're going to choose the way in which they work* ***efficiently****. Let's say their tank holds 50 cubic litres and a barge of SAF is about 10, then maybe they're going to go for the one on five, because that means they can put one barge of SAF on there and then four barges of normal fuel, and* ***that's just economically efficient****."*

> **FS-1:** *"They [fuel producers or suppliers] would of course like to keep it* ***efficient and cost economic process*** *and then it is good to* ***blend as high as possible*** *percentages then to lower the conventional jet fuel share of the deliveries further in the supply chain, because SAF is more valuable or expensive. So from that perspective you want to maximise the share of SAF at the point of blending, because there are then of course, blending tanks, pipe works and facilities that have been needed to be dedicated or segregated for the blending."*

In the above statements, EX-1 and FS-1 describe what "supply chain optimization" ultimately boils down to: taking into account the regulated SAF blend limits (and production uncertainties previously mentioned), logistical processes are configured in such a way as to optimize profit margins. FS-1 notes that this usually maximizes the SAF blend percentage in order to reduce transport of conventional fuel. Therefore, as will be apparent from the following statements by FS-3, OEM-1, and OEM-2, such logistical processes could be further optimized if the regulated SAF blend limits were to change.

> **FS-3:** *"So you say you're increasing the blending wall to 70%, yes, that doesn't mean you need less infrastructure. You will be using the* ***same set of infrastructure****. If you say no blend tank, then in theory you would need less infrastructure. Then it really becomes* ***more efficient****."*

> **OEM-1:** *"If you want to have an actual segregated supply [...], you need to deliver the fuel physically to a fuel farm and there you could minimize - so instead of having three trucks, only two trucks by going from 33% to 50% blend. But in the grand scheme of things, it's a small part, I would say,* ***fine optimization*** *to minimise the cost."*

> **OEM-2:** *"There's some discussion as to when the blend ratio will be* ***eliminated****, in other words towards a* ***fully synthetic fuel****. Because to a certain degree, it's a* ***burden*** *because now you have to deal with blending. You need to have blending facilities, blending logistics. If you go to fully synthetic fuel, at least in the scenario that you can use a fully formulated pathway, blending requirements go away. You directly produce the fuel, which is compliant, so you don't have to blend it with a conventional jet fuel or anything like that."*

If the blending limit were to increase to a higher percentage - taking into account the production uncertainties previously mentioned - this could optimize logistical processes even further, as elaborated by OEM-1, although this would only be a "fine optimization". A more significant step, as suggested by OEM-2, would be to extend the blend limit to 100% such that any blending infrastructure and operations would no longer be necessitated, removing a burden from the supply chain altogether. This need for supply chain optimization, however, also exposes some key issues with current fuel supply methodologies, namely regarding "commingled logistics".

5.4.2. Commingled logistics

Influencing conditions: IC5

As explained previously, SAF is allowed to use the same means of transport as Jet A-1 when it complies with the outlined fuel specifications. It is able to be transported through the same pipelines, stored in the same tanks, and fuelled using the same fuel systems. EX-1 explains how this impacts the blend ratio.

> **EX-1:** *"Because there's multiple fuel deliveries - one from Shell, from Q8, from Air bp - but they don't have their own storage tank, they'll work with the* ***same*** *storage tank. [...] Even if you blend at the blending facility up to 37%, it's going into the pipeline or it's going into the fuel farm tank with 10 other batches. So it's going to be more and more and more* ***diluted****. So in the end, what goes in the aircraft is generally, sometimes going to be 5%, maybe 6%, but sometimes those can be 0%. And at average, you're looking at the 2%* ***because that's what we have mandated in Europe****."*

To elaborate on EX-1's point, because all SAF batches are transported through the same pipeline and stored in the same tank, the blend percentages are diluted along the supply chain. Although this makes the most financial sense, this suppresses the demand for higher blends of SAF because everything is diluted to the bare minimum mandated. In order to drive higher SAF blend ratios, either designated infrastructure would be required to transport higher blends of SAF or the market would have to be pushed to increase SAF blending. Because there are no financial resources available for the former (IC5), the increased benefits of higher blends of SAF could only be perceived when the mandate increases.

> **EX-1:** *"There's no differentiation in fuel spec for the different fuel suppliers, which is the reason why ASTM is so* ***strict*** *with that percentage. Because if you mess up, you do that for* ***the entire value chain*** *because the entire fuel farm is messed up. All of the aircraft are messed up. You've also got* ***enormous insurance issues*** *because you're also responsible for the fuel of other parties."*

To add onto this, there are tremendous liability challenges due to the nature of commingled logistics. If a single incident occurs, the consequences can be passed onto the entire aviation fuel industry. Therefore, high legal consequences and exhaustive certification processes are imposed in the aviation industry to mitigate such risks to the bare minimum.

5.4.3. Lack of infrastructure

Influencing conditions: N/A

When SAF complies with the specifications outlined by American Society for Testing and Materials (ASTM) standard D7566, it is declared as Jet A-1 under ASTM standard D1665 and is allowed to use the same means of transport as Jet A-1. This, in turn, ensures that SAF has almost no difficulty being moved across the globe and to airports. One exception case concerns land-locked states, which is briefly touched upon by EX-2 below.

> **EX-2:** *"They [the EU] want to have SAF at every airport, but we're also working with for example Budapest Airport. And there, there are no bio-SAF production plants, no blending, right? And so because of the* ***lack of infrastructure****, they have to truck or rail stuff from Central Europe [...]. So obviously the choice is very rapidly made to not do that. And then the EU is saying, 'yeah, but it's an incentive. They have to build the SAF refinery over there'. [...] So as we move towards other technologies, I think it's super important that we* ***develop more technologies*** *so we can really use different feedstocks and in central Europe or in mainland countries far away from ports, [...] so you can also produce SAF with* ***local feedstock****."*

When land-locked states are not connected to an international pipeline, such as Budapest Airport, and have no nearby SAF production facility, this complicates logistical processes for the airport as there is a lack of infrastructure. However, this does not necessarily pose a barrier, but rather an incentive for SAF producers to expand in Europe to fill in the few gaps that remain in SAF's infrastructure. In a similar vein, EX-3 notes how the regulations imposed by ReFuelEU aviation exercise pressure on current inefficient logistic processes in the following example.

> **EX-3:** *"It's amazing that we have a pipeline and, when it is blended, it can go through there. That's the* ***most efficient way*** *in terms of costs and energy that you have to put into it to get something from A to B. That system only ends at airports or military bases where it takes off in the air. So there is a* ***guarantee*** *that it will be used and that, in turn, results in climate benefits, so I think that has been organized amazingly. Rotterdam The Hague Airport, for example, has no connection to that pipeline system, so you have to drive there with trucks. Yeah, that is* ***inconvenient*** *but could possibly be overcome, but I think a pipeline to there would be* ***more efficient****."*

Amsterdam Schiphol Airport, one of the major SAF hubs across Europe, has two pipelines which deliver fuel. Rotterdam The Hague Airport (RTHA), on the other hand, has no direct pipeline connection, which causes fuel trucks to drive between RTHA and the nearest Jet A-1 supply location. With the introduction of ReFuelEU aviation and their aim to have SAF supply to every airport, this would also mean that dedicated trucks would have to drive with SAF to RTHA. The inefficiency of this logistical process due to lack of infrastructure is emphasised by ReFuelEU aviation, advertently exercising pressure to establish more connections to the Central European Pipeline System (CEPS) network and make both Jet A-1 and SAF delivery to RTHA more efficient.

5.5. Innovation-specific institutions and industry-wide regulations (F5)

Among all (f)actors under which high-blend SAF is analysed, the institutions and regulations of this technology are found to be the most recurring in interviews and analysis, with a total of six codes that have been identified. These are: "extensive approval processes", "national-regional fragmentation", "regulatory burdens", "intra-regional fragmentation", "unclear governance", and "inter-regional fragmentation". In the following sections, all codes shall be discussed.

Table 5.5: Rate of occurrence of codes under F5 (innovation-specific institutions and industry-wide regulations)

	Interview														
Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Sum**
extensive approval processes	3				1	3		3	3	1	3		1		18
national-regional fragmentation		7	3		1		2			1					14
regulatory burdens	1		3	1	1		1	1			1	3			12
intra-regional fragmentation		1			1						3	1		4	8
unclear governance	1						7								8
inter-regional fragmentation						1				1		3			5

5.5.1. Extensive approval processes

Influencing conditions: IC7, IC8

> **TRO-1:** *"I think in terms of barriers [to SAF adaptation and beyond the current 50%], [...] the biggest one is **safety**. So safety and certification. How do you know that this is going to be safe? [...] So a lot of it is a chicken and the egg problem because we need the entire industry to move a step **together**. And that's hard to do. So it's not that it's a conservative industry, that we don't want to change. It's just that doing it would bankrupt everybody, so you have to do it very **slowly**, unfortunately, and you have to do it in a way that's **safety compliant**. And I think the safety compliance part is the one that takes the **longest**, and it's also the most important."*

> **OEM-1:** *"Aromatic content can be reduced easily because the nitrile seals, they don't need 8%, maybe 6%. We recognise this, but this is just one part of the topic, material compatibility, but there are many others and we need to be **very careful**. We change this when we move away from conventional fuel. We do it step by step based on data, based on research. [...] In the long term, it may come, but we are still working on it and it will take some time. **Beyond your five years**."*

From the previous two statements by TRO-1 and OEM-1, a direct relationship can be drawn between long certification processes and safety. When an accident or aircraft crash occurs, this has a lasting negative impact on the entire aviation industry. Therefore, safe travel is warranted through exhaustive certification processes in the aviation industry, mitigating risks to the bare minimum. This, in turn, also results in very extensive certification processes. When it comes to introducing new technologies such as high-blend SAF, this challenges conventional norms which are proven safe, and the industry treads carefully and slowly into new territory to avoid future disasters (IC8).

> **INF-1:** *"Those processes [**with governmental bodies**] are simply slow. So the contact is fine and the interests are acknowledged well. Yeah, so that works fine from my perspective, it's just **excruciatingly slow**. [...] I don't think that we can accelerate that. It's simply about staying in the loop."*

> **INF-1:** *That the process is **long**, it's a common fact in the **petrol industry**. There are interests on all kinds of levels, so it's simply about waiting until a decision is being made."*

Although very similar, the statement by INF-1 above draws on the inherent characteristics of two other sectors to explain the duration of approval processes, namely, the government and the petrol industry. Concerning the former, government processes are inherently long because of bureaucracy, which requires navigating complex legislation with layers of approval to ensure fair policy-making. Concerning the latter, the petrol industry may also experience some inertia to account for complex risks and uncertainties that come with decision-making, as well as coordinating imbalances in power and interests between multiple stakeholder groups (IC7). To then combine the longevity of approval processes in the aviation industry, governments, and the petrol industry, it is only natural that the introduction of SAF is excruciatingly slow. And as INF-1 comments, "it's simply about waiting until a decision is being made."

5.5.2. National-regional fragmentation

Influencing conditions: IC7

In any mature industry, the regulatory landscape strictly dictates the rules by which the industry should play. Sometimes, such a landscape is composed of a single standard which is adhered to globally. Other times, this landscape can consist of multiple mandates and regulations, each of which conceives boundaries. And when such regulatory boundaries exist, they may also clash with one another. One such example is illustrated in the statements by AIR-1 below.

> **AIR-1:** *"In the Netherlands we have the ambition in 2030 to blend at 14% on behalf of the 'Akkoord Duurzame Luchtvaart'. Simultaneously, there is the ReFuelEU mandate and between those two is a* ***gap*** *[of 8%]. [...] It's been* ***difficult*** *to get other airlines on board to blend SAF on a* ***voluntary basis****. The ReFuelEU is a blessing and a curse, so to say, because it is also a great means to stimulate SAF demand and scale up production. Simultaneously, it is* ***limiting****. It shall be 2% until 2029 and 6% in 2030, so there is very little room in the meantime to have a linear increase. [...] In that sense, we are really dependent on the regulation. And like I said, that is* ***both a blessing and curse****."*

> **EX-3:** *"Until now, the government has not found a way to legally enforce to move towards that 14%. ReFuelEU was create to create a* ***level playing field****, so the Netherlands saying 'we want this', that's inconsistent with that. So then you have to look for other ways in which we can ensure that the blend goes up, that we can make that 14%."*

The Netherlands finds itself in a unique position as it aims to increase the use of SAF to 14% in 2030 - 8% beyond what is mandated by ReFuelEU aviation - determined in the Akkoord Duurzame Luchtvaart that was released before ReFuelEU aviation. However, because ReFuelEU aviation now prescribes SAF blend shares for fuel suppliers across all of Europe, the Netherlands has no legal footing to enforce higher percentages. In other words, the Netherlands as a country must look to other means to drive voluntary uptake of SAF, such as incentives and subsidies, but this in itself yields limited results because the EU is trying to create a level playing field across the European Union (EU). If an airline were to use more SAF without absorbing the costs themselves - under the assumption of the supply and demand model with perfect competition - their ticket price would increase, and consumers would be inclined to fly with another airline (IC7). Therefore, airlines are either inclined to follow only what is strictly mandated by ReFuelEU aviation to maintain a competitive position in the market, or absorb the costs of increased voluntary uptake so as not to affect ticket price. The latter option is further elaborated upon in more detail in section 5.7.2.

5.5.3. Regulatory burdens

Influencing conditions: IC1, IC7

As shown in the previous section, stakeholders may experience increased regulatory burdens due to conflicting frameworks. However, as will be apparent from the following statements, administrative processes also play a large role in this.

> **FS-3:** *"Well, if you look from the side of the airline, an airline flies to all kinds of airports. [...] And ideally, the airlines receive all kinds of documentation at the end of the year to deliver proof that an airlines has purchased and uplifted this much SAF that can then be used to reduce the claims under ETS, the costs under ETS. But if I am KLM in Europe, then I probably have 40 different fuel suppliers and I fly to 100 different airports. Then it could definitely be the case that [...] I get sent a lot of PDFs. We sent* ***thousands of these statements****, but I can imagine that the administration on the side of an airline and the translation to an ETS submission is* ***enormously complex*** *and* ***way too inefficient****."*

> **TRO-1:** *"Well, on a bigger scale, I think* ***digitalization*** *and* ***automation*** *is a huge issue. So with certification, that's another part of it. So what I mean by that is that a lot of the documentation having to do with this, with the certification process, is still* ***manual****. You can't get around it. [...] It's on the computer, but it's basically like filling out a physical form. There's no automated way of doing it."*

When attempting to claim Emission Trading System (ETS) allowances for using SAF, FS-3 explains that airlines have to manage thousands of documents. To complicate matters, these documents may range from a number of different fuel suppliers due to deviations in the supply chain when comparing different airports (IC7). As there is no standardised process yet in place, significant work has to be put into translating the proof-of-delivery into an ETS claim. As TRO-1 further notes, there is also a lack of digitalization and automation in certification processes in general (IC1), which requires a lot of additional manual labour to go through further administrative steps.

5.5.4. Intra-regional fragmentation

Influencing conditions: IC1, IC8

Because the Dutch ambitions are supplementary to the ReFuelEU aviation mandate in the context of fragmentation between national and regional mandates and incentives, their impact on the development of SAF is limited. A more detrimental example, however, can also be found at a regional level as noted by AIR-1, AIR-2, and INF-1.

> **INF-1:** *"The most important issue that is still not solved is SAF in a **banking system**. Aviation fuel is transported to, for example, Schiphol. You would think that that is a straight line, but it isn't. [...] Because of the banking system, what is physically inserted and bought by a certain airport or airline **cannot physically arrive** at the designated airport, that's not how the banking system works. [...] In the banking system, fuel is inserted and delivered in the most efficient way possible. And that's been accepted by all parties connected to the network; they do not receive the batch that they have bought, but the **volume** that they bought. [...] Physically there is no problem, [...] but it's problematic for the airlines both on an administrative basis and a financial basis."*

> **AIR-1:** *"If you blend at Rotterdam into the CEPS pipeline [...], it's pretty much **impossible** to retrace. It ends up in a fuel system, but where? For ReFuelEU, it's important that they can really see where the molecules are and that's why it's currently being transported by ship to Amsterdam and then from Amsterdom to Schiphol, so that those molecules are **traceable** yet **totally inefficient**. It would be a lot more effective if it could simply be mixed in the pipeline from Rotterdam. [...] A change has to take place to perhaps make something more **flexible**. And that can help with improving the efficiency of the entire supply chain."*

> **AIR-2:** *"So if you look at the system that we have now, which is the ETS and ReFuelEU, [...] you'll notice that there is a few parts that are **not matching up** with each other, and one being the SAF deliveries. So, EU ETS is not necessarily a fan of a mass balance mechanism or, for example, book and claim. ReFuelEU is a bit more **flexible**. The problem is, there is one mechanism that will grant you an incentive, and the other one that does not directly. So, of course, we have to focus on the mechanism that is pushing an incentive, which is through EU ETS, but it's not very flexible because they want to keep **traceability** of SAF to a certain level. I think there are more things that are not necessarily in line with each other because these two texts were not created by the same group of people. [...] It's **not clear** at the moment. We have to comply with both regulations and it's difficult to do so where you don't have the same guideline from both."*

As AIR-1, AIR-2, and INF-1 explain, there is a mismatch between the EU's ETS and ReFuelEU aviation which primarily concerns the delivery (and usage) of SAF across Europe. On one hand, current ReFuelEU aviation mandates fuel suppliers to deliver a minimum 2% SAF share of their total supply to European airports. SAF suppliers could make use of the CEPS network because this network - as noted previously by EX-3 - only ends at airports or military bases where it takes off in the air. In other words, ReFuelEU aviation is sufficiently flexible to allow a "mass balance mechanism" (AIR-2). On the other hand, there is the EU ETS. Under the ETS, allowances for CO_2 emissions can be purchased and sold between airlines, acting as a market-based mechanism, but airlines can also claim ETS allowances when purchasing SAF. However, to make these claims, the airline must prove that the SAF is physically delivered into the fuel system of a specified aircraft taking off from a specified EU airport for an ETS-covered flight. This rigidity of the EU ETS conflicts with ReFuelEU aviation's flexibility and the nature of the CEPS (IC1). As a banking system with branching pipelines that run across Western Europe, the traceability of a SAF batch cannot be warranted. Therefore, while fuel suppliers would be able to make use of the CEPS under ReFuelEU aviation, airlines will not be able to make claims under the EU ETS. As a result, transport through the CEPS is avoided altogether and the only other pipeline with no branching paths that leads to Schiphol, the ASP, can be used to transport SAF within the Netherlands. Because of the lack of coordination between ReFuelEU aviation and the EU ETS (A1), some SAF batches that arrive in the Europoort or the Botlek have to undertake less efficient means of transport for the fuel suppliers and airlines to still be able to make the claims. One of the primary reasons for this mismatch can be attributed to the fear among EU ETS policymakers who are afraid to lose track of the molecules if more flexibility is introduced, which would cause people to lose interest and trust in SAF (AIR-2) (IC8). Another primary reason ties into unclear governance as expressed by INST-2 below, as a lack of coordination (A1) between two parties results in a stalemate.

> **INST-2:** *"The different parties are always pointing at **each other**. In the Netherlands, it's an **international market** and those pipelines that run through Europe, everyone can put something in it and then it exits some place else. So then they [the Netherlands] say, 'yeah, we can't regulate this as the Netherlands'. On the other hand, Europe says 'well, we're not going to write everything out. The member states have to take a step themselves.' And well, you know what happens then: **nothing**, basically."*

5.5.5. Unclear governance

Influencing conditions: IC7

> **EX-1:** *"The decision-making process for going for either a Jet X or working within the Jet A-1 spec is currently very **unclear**. There's no clear governance. **There's no organisation in the world that makes a decision.** ASTM is the approval agency, right? So they say yes or no. [...] But it's **not in a position** to say "we're going for this pathway", "we're going for that pathway". You could say the OEMs and the aircraft manufacturers are in the best place to make that decision because they are the ones doing the research on this topic. But for them, it's also **not very clear**. They also don't feel like they want to make that decision because in the end, they don't produce fuel and they don't actually buy fuel. [...] They're just the ones that make the machines that work with it."*

In the previous statement by EX-1, they share concerns regarding unclear governance. While blend limits beyond 50% may be possible for some SAF pathways with increased research efforts, they are not actively pursued because there is no clear governance structure when it comes to making decisions. While Original Equipment Manufacturers (OEMs) could certify their equipment for low-aromatic fuels, they believe that they should not decide because they are too detached from the fuel industry. On the other hand, fuel suppliers can also press the blend limit, but this is not a primary focus for them as the SBC supply is limited to begin with (Section 5.3). Finally, ASTM, which prescribes such industry standards, holds no control over aviation rules and regulations, but rather the European Union Aviation Safety Agency (EASA) and Federal Aviation Administration (FAA) primarily do. This regulatory gap also leads to some frustration among policymakers, which is illustrated in the following statement by INST-2.

> **INST-2:** *"I didn't read ReFuelEU Aviation from A to Z, but I did not come across the abbreviation ASTM, so I don't think it's in there. I would like to say, 'guys, if it contains specifications that you deem important, **you should be able to take those up** as a government'. [...] It's nice and all, but who came up with it? Is it a safe margin? Could that 8% also be lowered? Where does it come from? So, that 8% volume aromatics is remarkable, the 50% SAF blend is remarkable, and actually we're really just a **plaything of the industry** who set up a document that you can buy for $120. [...] I think that if there are these kinds of limits for specifications, you should be able to put those down in legislation as a government."*

To date, although the industry heavily relies on the norm prescribed by ASTM (IC7), there is no European equivalent of the ASTM norm taken up in legislation, nor is there any reference to it.

5.5.6. Inter-regional fragmentation

Influencing conditions: IC2, IC6, IC7

To conclude on the analysis of SAF's fragmented regulatory landscape, the following statement is taken from FS-3:

> **FS-3:** *"The biggest hurdle now, or the biggest problem in the current European SAF industry or market, is how all regulatory framework are arranged and with that,* ***not configured*** *to each other. That is probably the biggest problem at the moment. [...] The coming 2, 3 years, a lot of similar frameworks will arise in Asia, but in Europe - and then, of course, you have a sort of overarching, your CORSIA, that's also there - but they are* ***totally not tuned to each other****. You read about that as well, [...] that an international carrier from Europe is flying to America. They have to buy SAF. They can claim it in theory under ETS, but they do not have any ETS exposure, so it's actually a sort of* ***value leakage****. That's what I think most people* ***struggle*** *with at the moment and that creates a* ***very inefficient industry****. That has nothing to do with physical molecules. It has to do with how those frameworks are not aligned with each other."*

In the statement above, there is an evident regulatory gap between Europe and geographically adjacent frameworks. One such example is the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), which is developed by the International Civil Aviation Organization (ICAO). While the scope of the EU ETS and ReFuelEU aviation is limited to the EU, ICAO is an international agency of the United Nations that aims to achieve the sustainable growth of the global civil aviation system. This framework and these requirements, however, are inherently different from the ReFuelEU aviation framework developed by the EU. As a result, EU airlines must ensure *double conformity* from 2027 onwards to both ReFuelEU aviation and CORSIA, not just for translating proof-of-deliveries to claims, but also to the different Sustainability Certification Schemes (SCS) enforced by the different bodies. For example, the EU utilizes the Renewable Energy Directive (RED) whereas ICAO utilizes CORSIA sustainability criteria. These discrepancies add regulatory burdens for fuel suppliers and airlines as different methodologies and regulations have to be navigated. Furthermore, as FS-3 notes, there is a leakage of value as EU airlines are limited to ETS claims for ETS-covered flights, which does not cover intercontinental flights. For such flights, airlines would instead have to look at compensation through CORSIA.

> **FS-2:** *"Look, at the end of the day we mustn't forget that the* ***competitive position*** *that we have with China is pretty difficult. Most facilities are* ***no longer being built in Europe****, they are being built in Asia. For logical reasons. [...] It's* ***cheaper*** *and* ***more accessible*** *in terms of regulations, permits, etcetera. [...] Eventually, those countries are probably going to install a mandate for blending and then there is a chance that those volumes will no longer be transported to Europe. That's possible."*

A second example, as illustrated by FS-2, shifts the focus to Asia. As opposed to boundaries of two regulatory frameworks clashing with one another, Asia has developed a lot of flexibility in its regulations. Europe's market climate is more challenging compared to Asia because of the restrictions imposed on feedstocks that can be used to produce SAF (IC2, IC3). As a result, more feedstock is available, and fewer regulatory burdens are imposed upon fuel producers, making it more attractive for them to install facilities outside of Europe (IC6, IC7). While importing SAF from outside Europe is not a problem as of now, it may pose a barrier in the future as Asia ramps up efforts to make its transport sector more sustainable.

5.6. Network formation and coordination (A1)

Concerning network formation and coordination, the actors and the coordination among them are analysed. Within this building block, the codes "collaboration and coordination", "conflict of interest", "lack of participation", "priorities" and "noise" are found. These are investigated in further detail below.

Table 5.6: Rate of occurrence of codes under A1 (network formation and coordination)

	Interview														
Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Sum**
collaboration and coordination			4		2	1	2	3			2	3	2	5	24
conflict of interest					1		2	1			4			2	10
lack of participation		1	1							1	1		1		5
priorities	1			2											3
noise					1							1			2

5.6.1. Collaboration and coordination

Influencing conditions: N/A

Collaboration and coordination among the network of actors is heavily intertwined with the formation of all other TIS building blocks. Some statements below by various interviewees illustrate the current state.

> **INST-1:** *"In any case, we take up **input from across the sector** where the needs lie, so we speak to many more sector parties about their needs and the questions that have been submitted to the government."*

> **EX-3:** *"In order to be able to properly set up such a policy and then ultimately implement and execute it, it would have to be set up in a **co-creation-like manner**, so that there is **real cooperation** between the industry and policymakers with **participation** and I think that is also something that works best. [...] What is now mainly done when the government develops policy is that there is a kind of period where people **can give feedback** on those policy developments. [...] They are often asked to organize stakeholder sessions, so that whatever is devised can then be reflected on with the group."*

> **OEM-1:** *"ASTM is working by **consensus** and everyone has to be at the minimum knowledge has to be shared so that any evolution of the spec can be **easily accepted**. So this research probably has to be done in an academic world and published openly."*

> **FS-3:** *"How that should work - and it's nice that it also happens this way in this industry - is through many **bilateral organizations**. So for Europe you have IATA [...] that includes both airlines and fuel suppliers and where they jointly look for an **industry-wide solution**. But on the other hand, you also have Fuels for Europe, which is an industry working group that I think includes almost all fuel producers and suppliers in Europe, so they are actually a kind of vehicle where a solution is sought that **works for an entire industry** and they then communicate with a DG-MOVE, for example for ReFuelEU, how that can be implemented. And of course, at some level, your I&W and your NEa of each European Member State, will also have a certain influence and a say in this."*

First and foremost, excerpts from INST-1, EX-3, and OEM-1 reveal that the development of policies is often executed through a co-creation process. Before enforcing new laws and legislation, policymakers collect feedback on policies from stakeholders across the industry to refine these. Secondly, although such regulations cannot be enforced by local governments, ASTM has developed a globally accepted norm because it prescribes regulations on the basis of consensus among the entire industry. Furthermore, FS-3 also discusses the presence of many bilateral organizations in the aviation industry, which encourages coordination among either different stakeholder groups (e.g. IATA) or individual actors in the same stakeholder group (e.g. Fuels for Europe), together with some involvement of competent authorities, to reach a shared solution which ”works for an entire industry”. When participants were asked who is responsible for taking up measures to overcome certain barriers to SAF adoption (see question 9 and 10 in Appendix C), three types of responses were most frequently mentioned: either regulatory bodies (FS-2, FS-3, INF-1), the entire industry (AIR-1, AIR-2, EX-2, TRO-1, OEM-2), or a co-creation process between industry actors and regulatory bodies in which the authoritative body takes charge (EX-3, FS-1, OEM-1). These results argue that a majority of the industry supports and pursues collaborative practices between actors, with regulatory bodies such as EASA or ICAO noted as the central actors to uphold such processes. In sum, these examples suggest a well-connectedness among actors in the industry with collaboration and coordination processes in place. However, despite such a connected network, there are also several relevant issues that are exposed with increased SAF adoption, as will be apparent in the next section.

5.6.2. Lack of participation

Influencing conditions: IC8

> **INST-1:** *”Well, it’s [ASTM] not a government standard. It’s actually the industry standard, purely on technical grounds for the work of the engines and so on. So as Member States, we actually have* ***no direct say or control*** *over that. We actually don’t concern ourselves that much with it. We know it is there, of course, but it is also* ***nowhere in legislation****, so to speak. [...] Anyway, as a government we are* ***not actively involved*** *in ASTM-adjacent discussions, for example in the discussions surrounding certification of new production technology for SAF.”*

> **OEM-2:** *”Some of them will, again, try to shy away from some of these because it’s almost like a* ***burden*** *for them. If they’re [airlines]* ***committed to environmental agendas*** *for the lack of a better word, [they] might incentivize the industry for such solutions like renewable solutions, because they’re committed to going to a more environmentally beneficial situation. Some airlines might think the other way, they* ***might not care as much*** *about the environmental aspect and economics might be a bigger consideration for them. Again, there’s a* ***mixed bag****.”*

In the first example, INST-1’s statement depicts a lack of participation between themself as local government and ASTM as an authoritative figure. This neglect, in part, can be related to the fragmentation in the regulatory landscape of the SAF industry. As different policymakers develop different standards without coordination among them, inter- or intra-regional conflicts arise (F5). In the second example, OEM-2 describes a lack of participation from airlines in transitioning to more sustainable alternatives, which can be primarily attributed to the price levels of SAF. At the end of the day, the aviation and fuel industry remains a cost-driven decision-making where sustainable options are traded off against their required investment (IC8), which is perfectly illustrated by EX-2, INST-2, and AIR-2 below.

> **EX-2:** *”I mean, fuel is a bit like wine. We often take this comparison because there are different ways of producing fuel and you can also* ***improve the quality****, but then it* ***costs more****, right? Like, it’s more energy, the process is longer, and requires more steps to make a better jet fuel, a better product. And in the end, we want to keep the cost low, so* ***it’s a bit of a trade-off between having a good, clean fuel [...] and keeping a cheap fuel.****”*

> **INST-2:** *”Look, the SAF factories in Rotterdam and elsewhere, of course they are also after* ***money****. They decide things like, ’we are going to do something’ or ’we are not going to do something,’ but at a certain point they also say, ’Yes, we have to start up or build such a factory, it simply costs a lot of money to make,’ and then you hope to get some of that back from subsidies. Or that you can sell the SAF in a good way, so that your investments are worthwhile. So ultimately,* ***everything revolves around money****.”*

> **AIR-2:** *"It's a debate between, let's say, what we want to set as targets from a **sustainability** perspective and what could be **financially** possible in the current economy."*

5.6.3. Conflict of interest

Influencing conditions: IC5, IC6, IC7

The trade-off between environmental impact and financial investments often comes paired with a high level of "conflict of interest" among different parties. The most notable statements are provided below.

> **AIR-2:** *"I think at a political level, it always depends on who you would talk to and in which room, because there is, I think, people that strongly believe that airlines should be the one that **foot the bill for that** [SAF]. [...] And I think what is complex is, in the end, as an airline, you are the end user of the product and you're always **expected to pay**, to **fix** a lot of the sector's ambitions. And we're not the business with the best **operating margin**, so it makes it harder. Rather than having a system where everybody can pitch in, in a way, and then you have a **healthier ecosystem**. But it is a difficult discussion and also with companies that are **very dominant** in the market. For example, if you talk to Shell in the Netherlands, Shell nearly has a monopoly. So there is an **imbalance** in the discussion and anything you can get from it."*

> **INST-2:** *"Well, we see that the sector is mostly thinking along the lines of, 'we have a limit or a standard, and we stay below that standard, so **we just do our own thing**.' On the other hand, you also have Schiphol, which says, 'we do have a lot of people working on the platforms there. And we also have people living nearby. [...]' So they are also struggling with, and **are torn between two ideas.** [...] The various parties look at it **from their own perspective**, sometimes a little bit about health and safety, but ultimately mainly about **money**. We are in an **international market** where, well, soon people will prefer to fly somewhere else because kerosene is cheaper there, or because we in the Netherlands just have to lower the sulphur content or increase the SAF share. So, they are trying to keep generating their own revenue."*

As explained by INST-2, because the aviation industry is an international market where airports and airlines fiercely compete with one another (IC6), discussions concerning sustainability are often met with reluctance to ensure that the players retain their competitive position and generate sufficient revenues. As AIR-2 further notes, to then implement such radical changes has people often pointing to other actors in the industry, such as airlines, to "foot the bill" and "fix the sector's ambitions," who have been noted to be incapable of doing so (IC5). This relationship is further affected by the power and influence that certain actors hold over others in the industry, which, as AIR-2 explains, results in an imbalance in discussions (IC7).

5.6.4. Priorities

Influencing conditions: N/A

Under the scope of network coordination, an interesting code that developed during analysis of the interviews regards "priorities". The aviation industry recognises that there are a manifold of things that need to be done, but only limited resources available. These are discussed in the statements below.

> **EX-1:** *"And I think there's also a question of - and then it becomes more **political** - do you want to focus on this? You have **limited resources**. Are you going to focus these resources on increasing the amount of SAF within that big bucket and just going for quantity? Or are you going to put your efforts, your resources, your people on increasing that blend percentage? And my humble perspective is that the quantity needs to go up before we can talk about the quality too much."*

> **EX-2:** *What is actually the **priority** now? Because even Airbus was at some point like 'oh, we can definitely retrofit all our aircraft to make them 100% SAF compatible, but we're not producing that much SAF'. So, and as long as there is **no incentive** to fly on dedicated blend ratios and like higher blend ratios, there is no benefit for airlines. So who's going to fund all these retrofitting activities? So yeah, it's just a matter of **priorities**.*

> **FS-3:** *"And I think that in all these things that the industry has to do, that on the priority list "blend ratio up", "blend ratio down", that that is **not on that priority list**."*

Whereas EX-2 remains impartial, EX-1 and FS-3 express a belief that the blend ratio, although certainly one of the things that the industry needs to work on, is not significant enough to be considered of having a high priority. In both examples, this is due to the nature of the product's complementary infrastructure (F4): whereas EX-1 reasons from the perspective of commingled logistics in place, FS-3 attributes this to the limited impact on supply chain optimization. Altogether, however, they believe that fuel supply methodologies must change first. That begs the question: what *is* the priority? This shall be discussed in further detail in section 5.8.

5.6.5. Noise

Influencing conditions: N/A

As discussed previously, some stakeholders are assumed responsible for fixing the sector's ambitions when they are incapable of doing so by themselves. This finger-pointing between stakeholders can be better defined as "noise". When FS-3 was asked what one thing they would change about the SAF industry, their response was as follows.

> **FS-3:** *"I would then say it is ultimately about the **communication** between the various entities in this industry, to set up a platform for it or to make improvements. Over the past few years, there has been a lot of **finger-pointing**. 'That isn't going well.' 'That isn't going well.' 'You are doing that wrong.' and 'You are profiting from that.' 'You aren't delivering this.' 'That isn't possible.' 'It is too expensive.' But all that finger-pointing, all those problems and excuses, to set something up to reduce that, to create a kind of greater **transparency** in this industry... I think that would solve a lot. There is currently so much **noise** there, which I think is very **harmful** to the entire aviation industry and fuel industry."*

To conclude, while a large connectedness among industry actors is acknowledged and many organizations are established to encourage such collaboration, there is a lot of noise between different actor groups when it comes to transitioning to more environmentally friendly options such as SAF, because actors prioritise individual competitive position over a shared, collective benefit. As INST-2 has noted previously, by shifting the responsibility away to the opposite party, "you know what happens then: nothing, basically."

5.7. Customers (A2)

The final TIS building block concerns the customer segments of the product. Concerning (high-blend) SAF, end-users could here be referred to either the airlines which purchase the SAF or the individual passengers of the airline which makes up the general population. According to the TIS framework, central to the adoption of the product by customer segments are sufficient knowledge, means, and willingness. These are discussed throughout the following subsections using the identified codes "limited voluntary uptake", "public perception and trust", "limited demand", and "low willingness to pay".

Table 5.7: Rate of occurrence of codes under A2 (customers)

	Interview														
Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Sum**
limited voluntary uptake		3	6	1	1									4	15
public perception and trust			2	2	1			2				1	1	5	14
limited demand	2							1	1	1		1	2		8
low willingness to pay		1	2	1	2									2	8

5.7.1. Limited voluntary uptake

Influencing conditions: IC5, IC6

Returning to the example of the fragmentation between Dutch ambitions and EU regulations where the Netherlands strives for an 8% SAF share in 2030 on top of ReFuelEU aviation's mandate, another alternative for airlines is to absorb the costs of voluntary uptake themselves. This concept is explored in the following statements.

> **AIR-1:** *"Airlines find it **very difficult** to properly include that voluntary SAF in their carbon reporting. Yes, that seems quite difficult."*

> **INST-1:** *"From an economic point of view, fuel suppliers will adhere to the mandates enforced in Europe, and it is quite **difficult** to persuade parties to go far beyond that if it also costs more, while it is actually the basic level on a voluntary basis. That does happen, of course, but that is essentially an **increased barrier**, so to say."*

> **AIR-2:** *"The 14% of the Netherlands might be **difficult** without any further incentives because even if the Netherlands is trying to do quite a lot to participate in a SAF ecosystem, at the moment it's not necessarily where SAF is the **cheapest**. [...] So if we have this **struggle**, I could expect that the rest of the industry would resonate with that. [...] If SAF still remains extremely expensive for us, we'll meet what we need to meet in terms of requirements, **but to do anything more, especially for a low cost, is difficult** to push towards your board or the revenue team where there is no actual revenue that you can make on SAF."*

As can be expressed by AIR-1 and AIR-2, airlines have a lot of difficulty with increased voluntary uptake. This is because airlines find themself in an international market where competition is fierce (IC6) and limited funding is available (IC5). Therefore, airlines are inclined to follow only what is strictly mandated by ReFuelEU aviation to maintain a competitive position in the market. However, AIR-2 also notes that "if production would ramp up" and "would be more affordable", it would open up a lot more possibilities. However, as INST-1 explains, fuel suppliers are equally cautious with increased production. Similar to airlines, they take on a reactive role rather than a proactive one, producing only as much as they are certain will be consumed.

5.7.2. Public perception and trust

Influencing conditions: IC1, IC2, IC9

> **EX-2**: *"Yeah, I think there are two worlds, the people who know about SAF and the people who don't know about SAF. And we see that **the more people know about SAF, the more inclined they are to purchase SAF** or would like to invest in it and to **trust** it. They understand what it is, they believe in it, and **they want to support the development of SAF**."*

To build a sufficient level of knowledge about the positive impact of SAF and increased blend ratios, the perception of the general public must be guided in a positive direction to build trust, so that customers are willing to pay for the product. AIR-2 elaborates on these concepts.

> **AIR-2:** *"It's very difficult to explain it to a customer because we're very **limited** in terms of the type of communication we can make [...]. So, we want to communicate on sustainability, on SAF and what we do. It is extremely difficult because we have to **comply with a lot of different rules**, some that are logical, some that we're thinking, 'okay, these are just **hindering** us to communicate with our passenger'. But it is also difficult for a passenger to **trust**, let's say, big corporates. You always have this issue, not only for SAF. And we just have to find a way to make it **clear** and to have communication that also works in the guideline that is given to us."*

> **AIR-2:** *"I think it's just a broad issue of supply chain and the **risk is quite big**, because if our passengers do not **trust** that we are using SAF and that SAF is somewhere in the supply chain, then we could have a similar issue as with emission offset in the past where consumers **lost trust** in this system and it did not work in the end. And we don't want that for SAF, so…"*

> **EX-2:** *"I have a friend who commutes very often to Zurich and the company bans all the flights. So he has a company car with a card to pay for gas, so he has to drive to Zurich alone. I did the CO_2 equivalent calculation, flight versus car, and it actually **doesn't make sense** to drive alone. But the policy says, oh, is it environmentally friendly to fly? **So we are not really educating people well.**"*

As is apparent from AIR-2's statements, it is difficult to communicate and build trust with the general public for three primary reasons. First and foremost, as illustrated by EX-2's statement, the knowledge and awareness of environmentally-friendly alternatives for means of transportation by the general public is low (IC1), which makes interfacing with everyday passengers concerning SAF difficult to begin with, even in layman's terms. Secondly, however, this is complicated by the limited means through which communication with passengers is possible, because there are certain restrictions imposed by consumer laws to not mislead customers. This is directly tied to the third and final reason, which concerns greenwashing incidents in the aviation sector (IC9). Previously, public trust in the sector has been harmed after deceptive marketing strategies were used to make flights appear more sustainably beneficial, with airlines incurring reputational and financial losses. Consequently, airlines must now take extra caution in their means of communicating so as not to further harm public perception while retaining and building trust in SAF technologies. This is especially difficult when negative signals from the SAF industry continue to be emitted to the public (IC9), as is apparent from EX-2's statement below.

> **EX-2**: *"But there is also a lot of **bad publicity** around SAF. [...] So I think to build a bit more **trust** around this industry, it's important to have something super solid where there is something **fair** and **transparent** that works well."*

Although airlines are the focal point of communication with the general public, it can be argued that the entire industry is responsible for raising awareness and building trust. More interestingly, it was found from interview data that building trust and raising awareness as proposed by the TIS framework is not focused solely on the consumers (or end-users) such as airlines and passengers, but also all other actors inside the SAF ecosystem. This is argued using the statements below.

> **TRO-1**: *"People are now shifting focus more towards e-SAF, which was sort of like the **ugly duckling** of the transition world because you're still producing emissions. And now that ugly duckling moniker, that's sort of like, 'oh, we don't really want to touch it. We were more focused on completely zero, net zero'. And now we see more of a 'they're willing to touch it now'."*

> **OEM-1**: *"And it's very important because **we have been a bit guilty in this**, saying SAF is easy because SAF is drop-in. So all the research, all the money in clean aviation or EU funding for research has gone into more disruptive stuff like hydrogen aircraft."*

> **EX-2**: *"Even the startups and the companies who want to develop new production sites, they need the **trust of investors**. They need to show that there will be the **demand** and people are **ready to pay** that much and so on."*

> **INST-1:** *"There have been both **positive** and **slightly less positive** messages from the sector in recent years. The cancellation of Shell and BP's SAF factories in Rotterdam is obviously not a favourable development. At the same time, you also see that there are also parties that are still making plans and actually implementing plans for SAF in the Netherlands. [...] So yes, the sector takes it seriously that these are fairly clear mandates and Member States are of course in favour of us being able to scale up SAF with those mandates."*

In the first two statements, TRO-1 and OEM-1 explain how initial sustainability efforts in the aviation industry were largely focused on other technologies such as electric or hydrogen-powered flight, because actors in the aviation industry perceived SAF as a less beneficial technology, or as a technology that would require less time and investment (IC1). Because the feasibility of such alternative options is now deemed low in the short term by various actors in the industry, who have simultaneously voiced concerns regarding SAF's development, the focus has significantly shifted toward SAF to reach climate goals. Consequently, SAF development efforts such as research, funding policies, and volume expansion are scaling up. To establish the latter, as noted by EX-2, fuel suppliers and startups must secure investments from e.g. private investors, which in turn requires establishing certainty in the SAF market that there will be sufficient demand because investors assume a return on their investment. This market certainty is similarly driven by events and incidents such as the closing of Shell's SAF factory (IC9), but perhaps more significantly by the policy certainty issued through mandates and incentives by governments (IC2). This, in essence, captures the knowledge and trust-building processes that pertain to all actors inside the SAF ecosystem.

5.7.3. Limited demand

Influencing conditions: IC7

As the previous section outlines, private investors require certainty that there will be sufficient demand by airlines and passengers in order to finance the upscaling of SAF volumes. The following statements elaborate on such a demand for SAF blends above 50%.

> **EX-1:** *"Currently, the airlines, outside of their few researchers, **aren't asking for higher blends** specifically. They are **asking for SAF**. And only when they get to a demand - let's say KLM says 'I want 51% SAF next year' - will they start thinking about 'hey, I actually want to be able to get a higher blend percentage' or 'I want to have Jet X'. Until they reach their limit of the amount of SAF that they need in general over their entire fuel product, the demand remains a **challenge**."*

> **FS-2:** *"There is also **too little incentive** to investigate that, because that 50% blend wall is **not a problem** in practice at the moment."*

> **FS-1**: *"But of course there is then the fact that currently if we also reflect this to the ReFuelEU mandates, for example, **the blending wall will come there also at some point**, if you remember those percentages. So at some point we need to be at 70% of SAF content. So is it already then 2030s or 2040s at least when these higher blends should be allowed? Or is it so that the 100% SAF is considered to take the share?"*

> **OEM-2:** *"There is no direct effort right now for semi-synthetic aviation turbine fuel to go above the currently allowed blending limits, which is mostly 50%. [...] There's the fully synthetic fuel effort going on, but in terms of semi-synthetic, [...]* ***there's no effort or anybody pushing for that*** *in the industry. [...] The others who are limited to 50%, their focus is to put their commercial facilities on the ground rather than trying to increase the blend ratios or anything like that."*

As explained by EX-1 and OEM-2, there is no demand from airlines for SAF blends above 50%, partially due to the aforementioned issues identified under the product's complementary infrastructure (F4), but also because quantity is taking priority over quality (F3). Furthermore, provided FS-2's and FS-1's statements, because the industry experiences no complications when complying to both ASTM norm's (which imposes a blend ratio of no more than 50% for the majority of SAF pathways) and ReFuelEU aviation's mandated percentages (which in 2030 will only demand a 6% share of SAF), there is too little effort put into developing higher blends of semi-synthetic SAF (IC7). However, as OEM-2 and FS-2 note, there are efforts underway for fully-synthetic SAF, i.e. 100% SAF blends, acknowledging the environmental impact that higher blends of SAF have on flights. This research is currently still underway, however, meaning all efforts to scale up SAF concern blends below 50%.

5.7.4. Low willingness to pay

Influencing conditions: IC5, IC6, IC7

Voluntary uptake can also be analysed through the lens of passengers. In this section, the concept of a passenger's "willingness to pay" is explored in the statements below.

> **AIR-1:** *"Back in 2024, we looked at what it would actually cost if we implemented a 2% blend, what would that cost an airline and a passenger? Well, the conclusion was that it's about* ***€1 per seat****. What are we talking about, you know? Airlines often claim that it's all too expensive, but as far as I'm concerned:* ***it fits within the margins****. [...] Airlines don't agree, but if you look at the overall picture and knowing that people want to fly: demand is only increasing, we are all becoming more demanding, so yes,* ***if we all have to pay a few extra euros for that SAF, well, how bad is that?****"*

> **INST-1:** *"That blending obligation is increasing to the same level across Europe, so yes, ultimately, a ticket paid by a passenger or customer consists of these fuel costs to a significant extent. In my opinion, [...]* ***fuel costs will eventually largely come down to the ticket price****, because ultimately all stakeholders have to make a* ***profit*** *- at least the airlines, the fuel suppliers, and the producers. Ultimately, that price is* ***passed on to the person buying the product.*** *Those percentages are currently 2%, but soon they will be 6%, 36%. Certainly after 2030, it is heading towards quite* ***serious*** *percentages."*

> **INST-1:** *"There are some parties, definitely companies and governments, that already* ***blend more*** *or* ***pay more for blending****. For instance, we fly on 100% SAF [...], so as the government we are also in favour of the use of SAF when government personnel fly for business trips, in which case* ***extra is already being paid*** *or purchased outright. The same applies to some companies that do the same."*

> **EX-3:** *"I think what also plays a major role is - suppose we had much more of it - the price of SAF is probably still higher than that of fossil fuels. In any case, quite a few projections also show that the price* ***will remain high*** *for the coming years. [...] Ultimately, an airline has to pay for it too. They don't make much margin to begin with, so they probably* ***won't pay themselves****. They will* ***pass those costs on to customers****, meaning that customers will have to pay for it as well. I think there is still a big* ***challenge*** *there, but that is also easier said than done, that people have to get over the fact that it is going to become a bit more expensive."*

> **AIR-2:** *"The fuel is indeed a big part of our of our costs, and we try to* ***absorb*** *as much as possible to not put it on our passenger. And we know that the more SAF we have to blend, at some point, if we're the only one paying for it, we have to* ***transfer*** *part of it, like any other tax that you would have, as an airline."*

To summarize, airlines such as AIR-2 currently absorb the majority of the costs incurred by the mandated uptake of SAF to maintain their competitive position in their market (IC6). However, as mandated percentages will grow to 6% in 2030 or 20% in 2035, AIR-2 admits that these costs will have to be partially transferred to the passengers (IC5). This also aligns with statements from other participants, who expect the costs to be partially (INST-1, AIR-1) or fully (EX-3) transferred to the passenger. AIR-1 proceeds to note that this should not pose a problem because the demand among passengers will continue to increase, but EX-3 argues that this may yet prove to be a challenge (IC7). When differentiating between different aviation segments, AIR-1 also notes that commercial airlines have a lower willingness to pay for SAF than Business Aviation. This is confirmed by INST-1, which elaborates on their company policy to fly with 100% SAF and that a similar policy is adopted by other companies and governments.

5.8. Closing summary

This section summarizes the findings of the chapter. For the product, a description of the status of each TIS building block is provided alongside any relevant influencing conditions in item 5.8. This is also summarized in Figure 5.3 below. Before doing so, however, the product needs to be redefined in section 5.8.

5.8.1. Redefinition of the product

At the beginning of the chapter, the product was defined as **SAF with blend ratios above 50%**. During the interviews, however, it was found that the 50% blend wall holds little to no priority among ecosystem actors because of three primary reasons:

1. **Insufficient quantities:** Although meeting the currently mandated blend share of 2%, Europe struggles to upscale production in the future at the same speed as the mandate. Currently, there is too little SBC available to achieve high blend percentages in the first place.
2. **Regulatory limits:** ReFuelEU aviation mandates a blending share of 2%, which will gradually grow to 70% by 2050. Due to the fierce competition and limited funding mechanisms in the industry, this mandate closely resembles the share of SAF consumed by EU airlines. Thus, higher SAF shares (and consequently higher SAF blends) would only be warranted by an increase in the mandated blend share, which would only pose a problem in the long term.
3. **Limited impact:** High-blend SAF itself may be more environmentally beneficial, but breaking the blend wall would still have limited impact. Due to current fuel supply methodologies where high-blend SAF batches share the same supply chain as low-blend SAF batches and Jet A-1, high-blend SAF batches are diluted to the bare minimum mandated by ReFuelEU aviation along the supply chain.

This research argues that the blend wall is not the main challenge to the SAF industry but rather one of the many tools that can be - and already is being - developed to unlock future uptake of SAF altogether. Although the impact of bypassing the blending limit could be further scientifically investigated to argue for its importance, this lies outside of the scope of this research. Rather, the research favours a more pragmatic analysis which aims to remedy the key issues of the SAF industry. Therefore, the product shall be simply redefined as **SAF**.

5.8.2. Status of TIS building blocks and influencing conditions

Below, a summary is provided of all findings per TIS building blocks from which a status is concluded. An overview of the TIS (f)actors is displayed in Figure 5.3.

F1 - Product performance and quality: **Partly Compatible**

The performance and quality of the product is arguably well underway. Despite uncertainties in production with regards to the variability in feedstock and the limited control on properties during blending, SAF can already be used inside the existing aircraft fleet by taking sufficient safety margins into account. However, due to the aromatic content typically found inside jet fuel, most SAF blend limits are currently constrained at 50%. While aromatic-free or low-aromatic fuels would be more environmentally beneficial and could possibly be implemented through the Jet X specification, they are not yet feasible under current regulations, as this would require significant changes to be made to the aviation industry and its existing infrastructure, which is why drop-in alternatives are preferred.

F2 - Product price: Incompatible
The price of the product is in no position to compete with competitive products. The most commercially available SAF, HEFA, is still at least twice as expensive as conventional Jet A-1. This cost is attributed to the processing of feedstock and conversion into fuel. Such processes are also energy-intensive, which further drives up the price when little electricity is available. Because other technologies still lack maturity and cost optimization with respect to HEFA, producers continue to rely on HEFA until its feedstocks run out. Meanwhile, airlines operate under very small margins, meaning the price gap cannot be covered by the consumer.

F3 - Production system - Incompatible
Although currently meeting the ReFuelEU aviation mandate and being positioned in an oversupply market, there is a large concern that production systems in place will not be able to keep up with the speed at which the mandate increases. Currently, Europe has to rely on SAF volumes produced outside of Europe to meet the mandate, which means that it will become more challenging to meet the mandate when the SAF market outside Europe further takes off. Inside Europe, it takes too long to construct new facilities as well as pool enough financial resources to install the facilities, partially due to unforeseen technological challenges because SAF is still a novel product. In addition, e-SAF technology has such a low TRL that it is likely that required e-SAF volumes will not be met in 2030.

F4 - Complementary infrastructure and services: Compatible
When certified, SAF is allowed to use the same means of transport as Jet A-1. Therefore, a majority of the infrastructure is already in place, with any remaining gaps being further remedied with the introduction of ReFuelEU aviation. A minor barrier that remains largely concerns the SAF blend ratio. Fuel producers optimize blending operations by maximizing SAF blend percentages, which could be made more efficient by raising the blend wall. Due to the nature of current fuel supply methodologies, where all SAF batches are stored in the same tanks and pipelines together with Jet A-1, blend percentages get diluted, which limits the environmental impact of SAF. Furthermore, this introduces tremendous liability challenges.

F5 - Innovation-specific institutions and industry-wide regulations: Partly Compatible
Although there are policies that currently govern the SAF economy, the governance structure in the SAF industry is still partially unclear. This especially impacts SAF blend percentages as there is no clear governance which decides how to raise the blend limit, with there being no European equivalent of the ASTM norm taken up in legislation. Policies that do exist - in the EU notably EU ETS and ReFuelEU aviation - are not tuned to each other due to a lack of coordination. A lack of flexibility in the EU ETS combined with limited traceability of SAF in a network of branching pipelines causes such modes of transport to be avoided altogether, which negatively influences SAF uptake. This conflict is not just limited to the EU and its Member States, but also outside the EU for ICAO's CORSIA, which causes a leakage of value because intercontinental and transatlantic flights are not covered by the EU ETS. On the other hand, there are notable regulatory gaps in Asia, which makes it a more attractive market climate for fuel producers to produce SAF. To add, there is no standardised process for translating proof-of-deliveries into ETS claims, which adds additional regulatory burdens for airlines. As a result of no standardization for administrative processes and lack of harmonization efforts between governing bodies, the industry functions enormously inefficiently.

A1 - Network formation and coordination: Partly Compatible
The aviation industry is well-connected with many collaboration and coordination processes in place, among which are globally accepted industry norms, bilateral organizations, and co-creative development of policies. Despite this, limited participation and coordination between certain actors can be perceived at times due to a conflict of interest. This especially concerns the sustainability transition and uptake of SAF, which is met with much reluctance by airlines who have limited financial means

available. Consequently, there is a lot of noise and finger-pointing in the industry as stakeholders continue to prioritise individual competitive position over shared, collective benefit.

A2 - Customers: Partly Compatible
Although the means for further uptake of SAF are readily available, the knowledge and willingness are still, to some degree, lacking. First of all, knowledge and awareness about SAF by the general public is low, with means to communicate by airlines limited. This is further complicated by public trust, which has previously been broken by cases of greenwashing and continues to be damaged by negative signals emitted from the SAF industry. This also impacts the actions taken by stakeholders in the SAF industry, which is why trust and knowledge need to be built not just among customers, but among the entire industry. Meanwhile, willingness to pay across end-users is scattered: airlines have limited financial resources available and are afraid to transfer the cost of SAF to their passengers. However, it is expected that they will ultimately have to foot the bill, and this will not be a large concern due to the ever-growing demand. Corporate customers under the Business Aviation and General Aviation segment have already shown that they are willing to spend more on SAF to reduce their climate impact while travelling.

F1 - Product performance and quality	**IC1**	IC2	IC3	IC4	**IC5**	IC6	**IC7**	**IC8**	IC9
F2 - Product price	**IC1**	**IC2**	**IC3**	IC4	**IC5**	**IC6**	**IC7**	IC8	**IC9**
F3 - Production system	**IC1**	IC2	IC3	IC4	IC5	IC6	IC7	IC8	IC9
F4 - Complementary infrastructure and services	IC1	IC2	IC3	IC4	**IC5**	IC6	IC7	IC8	IC9
F5 - Innovation-specific institutions and industry-wide regulations	**IC1**	**IC2**	IC3	IC4	IC5	**IC6**	**IC7**	**IC8**	IC9
A1 - Network formation and coordination	IC1	IC2	IC3	IC4	**IC5**	**IC6**	**IC7**	**IC8**	IC9
A2 - Customers	**IC1**	**IC2**	IC3	IC4	**IC5**	**IC6**	**IC7**	IC8	**IC9**

Figure 5.3: Status of TIS (f)actors

6 Comparative SBC Analysis

Whereas the previous chapter answered the first half of RQ2 - investigating types of barriers which prevent sustainable aviation fuel (SAF) blending beyond 50% - this chapter aims to answer the second half of RQ2: analysing whether these barriers differ across specific synthetic blending components (SBCs). In question 4 of the interview protocol (see Appendix C), participants were asked the following question:

> **Q4:** *Do you think that certain SAF pathways are more likely to achieve higher blend ratios than others in the aviation industry? Or can this be generalised across all pathways?*

This chapter primarily dissects the answers to that question, analysing the types of developments specific to different SBCs and revealing the future potential of certain pathways over others. To first have a general overview of all pathways and types of feedstock used for each pathway, every approved pathway under American Society for Testing and Materials (ASTM) standard D7566 is visualised in Figure 6.1, adapted from Bauen et al. (2020).

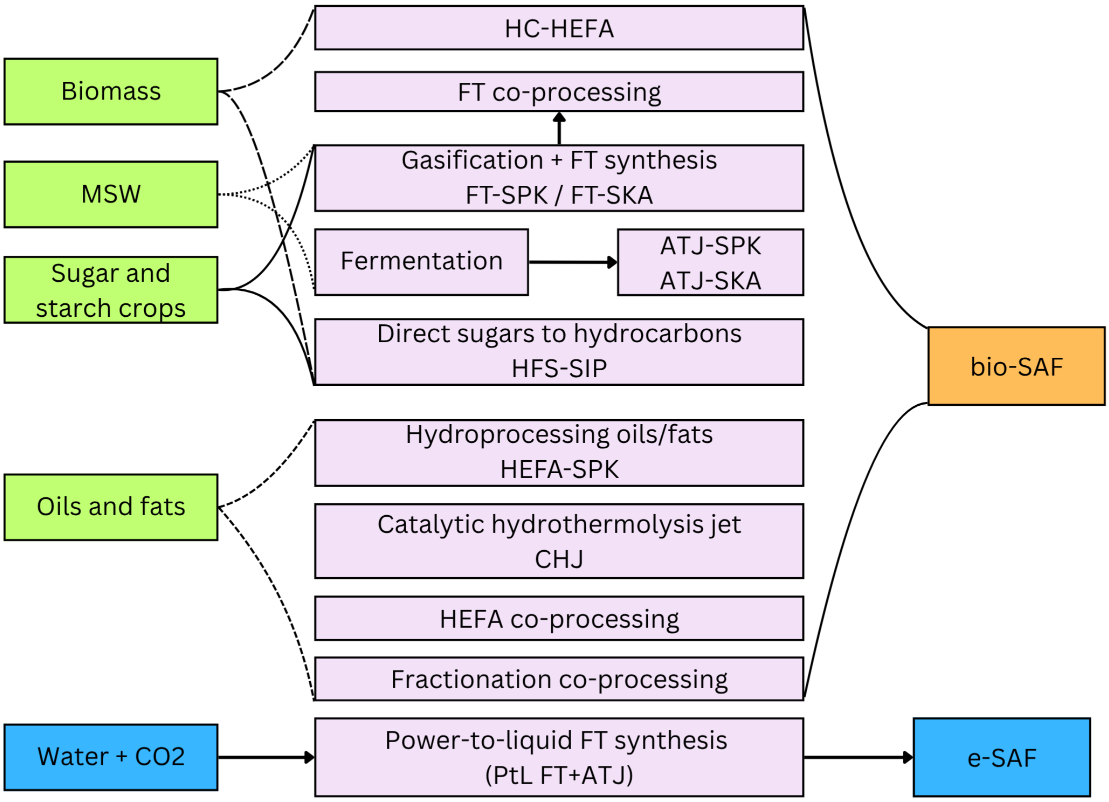


Figure 6.1: SAF pathways, adapted from (Bauen et al., 2020)

In Table 6.1 below, an overview of the rate of occurrence for all different SBC groups is shown across different interviews.

Table 6.1: Rate of occurrence of synthetic blend components (SBCs) in interviews

	Interview														
SBC	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Sum**
HEFA	3	4	5	1	8	14			2	8		11	8	1	65
PTL		4	8	1			6	10				11		1	41
ATJ			2		7	5			1	6		2	8		31
FT					8	1		1	1	2			1		14
CHJ					2				1	5					8
Other			1			1						1	4		7
HFS-SIP										2					2

From Table 6.1, it is found that alcohol-to-jet (ATJ), catalytic hydrothermolysis jet (CHJ), Fischer-Tropsch (FT), hydro-processed esters and fatty acids (HEFA), and Power-to-Liquids (PTL) were mentioned most frequently. This is supplemented by the analysis of two SBCs (see "Other") which are still in development but may prove beneficial in the future: methanol-to-jet (MTJ) and synthetic aromatic kerosene (SAK). Therefore, the scope of this chapter shall be centred around these seven main SBCs. Due to a lack of relevance in findings, HFS-SIP and all co-processing pathways will be neglected. Furthermore, discussions concerning HEFA shall be limited to HEFA-SPK as HC-HEFA is a highly specialized, niche pathway which is still produced on a small scale and only approved for blend shares up to 10%.

In the analysis, it was found that participants frequently argued from one of two points, depending on different metrics of achieving success. When participants discussed quality and purely focused on higher blend ratios, responses concerned the fuel's fit-for-purpose properties and certification efforts. However, when participants prioritised quantity, they instead elaborated on which pathway would be likely to achieve more quantities in the future. This then proceeds mainly from the arguments of Technology Readiness Level (TRL) and feedstock availability. Respectively, these two arguments are discussed in the context of ATJ, CHJ, FT, and HEFA in section 6.1 and section 6.2. Because PTL has its own mandated sustainable aviation fuel (SAF) share, it is disconnected from previous discussions and is therefore discussed separately in section 6.3. To conclude, a final section using the identified code "pathway complementarity" is discussed in section 6.4.

6.1. The influence of fit-for-purpose properties on blend ratios

In this section, discussions regarding higher blend ratios are revisited, but this time to compare SBCs and understand which SBC is more likely to achieve higher blend ratios, argued through the concept of fit-for-purpose properties. As noted previously, this shall be focused on ATJ, FT, CHJ, HEFA, and MTJ.

> **OEM-2:** *"HEFA-SPK, since it's an SPK, synthetic paraffinic kerosene, it* ***doesn't have aromatics, it has lower density****. So, since it has lower density, it is* ***not that easy*** *to meet all the property requirements of jet fuel, especially on the density for the finished blend at 50% blending with conventional jet fuel. [...] HEFA-SPK, sure, from an availability perspective, it is currently a little bit more attractive, but it has* ***tremendous challenges****.*

> **FS-3:** *"To get close to the current jet fuel specification, you need fossil fuel; you need* ***aromatics*** *that simply aren't in current* ***HEFA-SPK products****. And as long as that component or requirement remains in the jet fuel specification or is needed for the current generation of engines, you will need that aromatic from the jet fuel."*

> **OEM-1:** *"Probably after HEFA, the next one to come will be* ***alcohol-to-jet****. [...] These [ATJ-SPK] will be limited by the aromatic, exactly as HEFA, but for freezing point, cold flow properties like viscosity due to their much more isomerized molecular composition and their density, they are potentially* ***easier*** *to get to 50%."*

While HEFA-SPK - a synthetic paraffinic kerosene (SPK) - covers the largest supply of SAF across the globe, it faces challenges due to its paraffinic nature as noted by OEM-2 and FS-3. As OEM-2 proceeds to note, if HEFA-SPK were to be used unblended, this would require considerable certification efforts as well as large-scale changes to infrastructure to make it compatible with aromatic-free fuel. Although these facts also hold true for ATJ-SPK, this SBC has slightly higher chances to approach 50% due to its molecular composition.

> **OEM-2:** *"The airlines, operators, airlines are* ***not very enthusiastic*** *about that option [aromatic-free fuel]. They want a drop-in option, like a Jet A/Jet A-1 equivalent option. So, that's definitely the main current emphasis,* ***to pursue drop-in scenarios****."*

> **EX-3:** *"Three of them have the potential to be used* ***up to 100%****, because they also produce an aromatic component. And that is very handy in today's world of* ***'we prefer to have everything drop-in.'*** *And I believe those are an Alcohol-to-Jet (ATJ) pathway, a Fischer-Tropsch (FT) pathway, and a Catalytic Hydrothermolysis Jet (CHJ) pathway. In their current state, those three have the* ***potential*** *to still deliver an on-spec fuel even* ***above the 50% blend limit****."*

> **FS-2:** *"A number of those pathways yield a SAF type that* ***closely resembles fossil fuel****. Think of Annexes 4 [FT-SKA], 6 [CHJ], and 8 [ATJ-SKA] — off the top of my head — I suspect those will really be* ***100% approved*** *in the future. There are already work streams within the ASTM community looking into this."*

As noted by statements from OEM-2, EX-3, and FS-2, industry stakeholders such as airlines are most interested in drop-in options as this would require the least amount of change to the current ecosystem. Thus, SBCs that have significantly more potential to achieve higher blend ratios are those that could be used as drop-in options. Under current circumstances, these are likely to be synthetic kerosenes with aromatics (SKAs): FT-SKA, CHJ, and ATJ-SKA. CHJ is unique here in the sense that it does not use synthetically added aromatics, but naturally has striking similarities to that of conventional fuel.

6.2. The influence of feedstock availability and TRL on SAF share

In this section - following the findings in chapter 5 where quantity is prioritised over quality - SBCs are compared on the basis of which is more likely to contribute larger quantities to ReFuelEU aviation's mandated SAF share, argued through the concept of feedstock availability and TRL. The former is discussed in the statements below.

> **EX-3:** *"Ultimately, I think that* ***FT and ATJ have more potential overall than HEFA****, but yes, that is something I think everyone will* ***agree*** *on: that at some point, the supply of oily and fatty raw materials will simply* ***run out****. [...] I think the* ***raw material base*** *that can be used for those pathways [ATJ and FT] is a lot* ***larger*** *than the raw material base available for HEFA. And because of that, I do think it is* ***easier*** *for them to meet a larger portion of the fuel demand that will arise. Whether those are the most perfect technologies, I don't know."*

> **OEM-2:** *"So although there are a bunch of pathways that we are working on, predictions, projections kind of anticipate* ***HEFA transitioning into alcohol-to-jet****. [...] It looks like HEFA fuel will be relevant for a while, maybe another 5, 10 years, but the* ***feedstock availability*** *will become an* ***issue*** *with that. It reaches entitlement based on predictions of production and feedstock and availability, and that maybe alcohol-to-jet type of technologies, pathways, will start to play a* ***bigger*** *role."*

> **INST-1:** *"There simply* ***isn't enough raw material*** *such as frying oil to eventually keep up with demand. So out of necessity, there could actually be an incentive for those other streams. From our innovation programs and from the government, we are trying to see how we can already* ***scale up*** *the advanced raw material flows. [...] So we also try to give the sector a* ***push****. But yes, the sector must of course also be able to go along with this."*

> **FS-3:** *"I think one concern is how much feedstock will be* ***available*** *in the future. I think that is an* ***issue*** *the industry needs to look into for HEFA-SPK production. [...] Currently, especially in Europe, the list of permitted feedstocks is very* ***limited****, all very* ***safe****. And the moment there are eventually* ***shortages*** *[...], those prices will go up. And the moment prices go up, people will either find new sources of the permitted feedstock, [...] or it actually has to be the entire next generation of SAFs - so everything that isn't HEFA-SPK - needs to become so much* ***cheaper*** *that it can be used in direct competition with HEFA-SPK."*

As pointed out by all statements above, HEFA-SPK will be reaching a point where limited feedstock availability cannot keep up with growing SAF demand. Therefore, although HEFA-SPK currently is still the most widely used SBC, the SAF industry anticipates HEFA gradually transitioning into ATJ (OEM-2, EX-3) and FT (EX-3) over time, because they can produce SAF from a much larger raw material base. As noted by FS-3, if there is a shortage of feedstock for HEFA-SPK, fuel suppliers will then either look to new ways to produce HEFA-SPK at an affordable price, or other technologies need to be stimulated to compete on similar price levels as with HEFA-SPK. This is exactly what happens, as illustrated by

INST-1's statement, which comments on the stimulation of ATJ and FT technology through government subsidies to make use of advanced raw material. Surprisingly, CHJ is not mentioned here. On the topic of stimulation of novel technology, the next group of statements further discuss technological readiness.

> **OEM-1:** *"The **optimised** product we have today is an HEFA-SPK, because it's the **lowest CAPEX-intensive** that you can imagine - and co-processing would be even cheaper - but from what you use as blend component, this is the **cheapest**, even if the used cooking oil is quite expensive, you get to the cheapest blend component you can probably get on the market."*

> **EX-3:** *"Unfortunately, those three technologies [ATJ-SKA, CHJ, FT-SKA] are **not really at a very high TRL level**, meaning they **don't contribute significantly** to the fuel pool. However, for that technology production, for those technology pathways, you do need **different raw materials** than for the HEFA pathway."*

> **INST-1:** *"The downside is that the European blending obligation makes **no distinction** between the different types of biofuels. For instance, there is a sub-obligation for e-SAF, but the main obligation applies to SAF in general. And there is no distinction between fuels under the current obligation. HEFA-SAF is currently the **cheapest** and **most developed**. And the streams that still need to be developed are somewhat more **expensive**. Because there is no distinction between them, those streams are also only **minimally stimulated** as long as there is still sufficient HEFA."*

As noted by OEM-1, HEFA-SPK has attained the highest TRL among all pathways, meaning it is the most optimised production method which offers the cheapest SBC on the market. Meanwhile, ATJ, CHJ, and FT technologies are still underdeveloped with respect to HEFA-SPK - especially the SKA-type fuels (EX-3). Because ATJ, CHJ, FT, and HEFA all fall under the same mandated share of bio-SAF, ATJ, CHJ, and FT are minimally stimulated because they are underdeveloped and more expensive, at least until HEFA-SPK production runs dry. Therefore - to return to INST-1 and FS-3's earlier statements - such pathways need to be stimulated to be able to compete with HEFA. However, although CHJ is mentioned alongside ATJ and FT as a possible contender for higher blend ratios, it does not receive as much attention concerning subsidies.

6.3. Paying the price for power-to-liquids

A pathway which is exempt from the competition between ATJ, CHJ, FT, and HEFA is PTL, because there is a sub-obligation under ReFuelEU aviation specifically for e-SAF, the SBC produced from PTL. With regards to discussions concerning e-SAF, these only pertain to the upscaling of quantities with the goal of simply meeting ReFuelEU aviation. Thus, technology readiness and knowledge are again explored alongside some closing statements of industry stakeholders on whether ReFuelEU aviation is feasible to meet.

> **FS-3:** *"E-SAF is an **entirely new technology**. It truly is the next generation of molecules. **Not a single plant has been built yet.** I believe one or two parties might have made an effort for a very small production facility in South America, or North America, or the USA. But to build such a facility, [...] you are really spending 2 to 3 years on commissioning as well."*

> **INST-1:** *"We are looking more often [concerning subsidies] at e-SAF and advanced biofuels that are **less developed**, attain a **high price**, and have **higher development costs**, because such a plant simply costs more than a billion to develop, and it is also a **long process** until that stage is reached, or at least will take a number of years."*

As shown above, PTL is arguably one of the pathways with the lowest TRL, with very few operational productions. It is underdeveloped, more costly, and also takes a lot of time and investment to put into operation. Similar to ATJ and HEFA, INST-1 thus notes that subsidies are also more often designated for upscaling of e-SAF.

> **INST-1:** *"In the Netherlands, due to the climate and space, you do see that certain feedstock types and certain types of SAF are more promising than others. E-SAF is difficult in the Netherlands due to* ***high energy prices****,* ***hydrogen prices****, and* ***limited space*** *for electrolysis, but we are looking at, for example, importing* ***methanol*** *as a feedstock or intermediate product for e-SAF."*

> **OEM-2:** *"In terms of availability or the potential to produce renewable fuel into the field, et cetera, maybe a few things could be said. One of them is* ***methanol-to-jet****. [...] If everything goes all right, we will be able to add methanol. Now, why am I bringing that up? Because the methanol industry seems to have a* ***great potential*** *to introduce quite a bit of feedstock. Basically, methanol into SAF production. So, from that perspective, there's some enthusiasm around, you know,* ***enabling methanol as an allowed feedstock*** *for alcohol-to-jet."*

> **TRO-1:** *"That's [****electricity cost****] going to end up affecting how much it'll [e-SAF] cost per liter, like your cost per liter, because it takes a* ***large amount of energy*** *to make e-SAF. And if you want it to be competitive to the cost of Jet A-1, then you're going to have to lower your energy cost. [...] So that is another huge hurdle. The Netherlands is* ***not exactly cheap*** *when it comes to energy cost. [...] A helping hand in the regard to energy, I think, is a big one because direct air carbon capture is really expensive. You know, doing Fischer-Tropsch is super expensive. Electrolysis is one of the most* ***energy-intensive processes*** *you can use."*

In terms of feedstock availability - although the pool of raw materials which makes up renewable electricity and (captured) carbon dioxide may be immensely large - such resources are very costly to source and take up considerable space. Thus, as noted by INST-1, e-SAF is hard to produce in the Netherlands. This is further elaborated by TRO-1, who notes that an energy-intensive process like PTL could only be competitive if the electricity cost is also lower. Possibilities, however, arise with the current development of methanol-to-jet (MTJ), which allows methanol as an additional alcohol in ATJ-type fuels and could be used as an intermediary product for the production of e-SAF. Methanol can be sourced from a pool of more accessible feedstocks (OEM-2), and is also easier to import to countries such as the Netherlands (INST-1). Nevertheless, MTJ remains an immature technology that still needs to be approved, which complicates e-SAF development in the short term.

> **INST-2:** *"That [e-SAF] is nowhere near up to speed yet, so we need to have 1.2% by 2030 [...].* ***I don't think we'll make that.*** *And that is going to be a real problem. So kerosene will become considerably more* ***expensive****. There will be a lot of demand for it. There* ***isn't enough hydrogen*** *to produce it. [...] They [the European Union] did say recently last month that 'we are really going to hammer on that e-SAF part, that percentage,' that it has to happen. I do foresee that they* ***will eventually give in*** *and say, well, given the difficult geopolitical circumstances, we will be a bit more lenient about that."*

> **FS-3:** *"To produce e-SAF molecules at all in 2030, or let's say between 2030 and 2035, that is already a* ***challenge****, let alone* ***producing enough*** *of what is needed. And then you also have your e-SAF trajectory, which also starts from 2030, 2031; that offers some flexibility, but the* ***ramp-up accelerates very rapidly****."*

> **INST-1:** *You see a lot of activity on e-SAF right now. That is logical, because obligations are coming into effect in four years that the sector must meet, and there isn't a single large e-SAF plant in Europe yet, so that is a* ***concern****. I am not worried, but I do still see* ***challenges*** *in scaling up advanced biofuels on time and getting that technology ready as well.*

> **AIR-2:** *"I think for HEFA I would not really expect a European Commission or the Netherlands to change your targets because we know that it might be difficult, but it is feasible. [...] For e-SAF, I think that could be different because* ***we don't necessarily see capacity*** *at the moment."*

To close off, the industry is sceptical about meeting the mandated e-SAF shares issued by ReFuelEU aviation in 2030. As illustrated by the statements above, different stakeholder groups (AIR-2, FS-3, INST-1, and INST-2) all show concerns or even believe that ReFuelEU aviation will be adjusted to incorporate lower e-SAF shares. Even if ReFuelEU aviation may "hammer on that e-SAF part, that percentage" (INST-2), technology readiness is too low, feedstock has limited availability or is too underdeveloped, and it takes too long to put e-SAF refineries into operation to be able to produce enough quantities in time.

6.4. Pathway complementarity

A descriptive code which closes off the chapter is labelled "pathway complementarity". The definition is twofold: the blending of multiple different SBCs to enable higher blend ratios, but also the co-existence of multiple SBC supplies to meet mandated SAF shares. Each is discussed in their respective paragraph below.

> **OEM-2:** *"Another pathway [...] to hopefully come soon is something we call SAK, synthetic aromatic kerosene. So that's* ***nothing but aromatics****. Just like SPKs are nothing but paraffins, SAK is nothing but aromatics. So it's missing the paraffinic fraction. It's just aromatic fraction. [...] Once that is qualified, it* ***opens up a way of blending*** *that component with already existing paraffinic blending components to get their fully formulated fuel."*

> **FS-2:** *"If you are going to blend HEFA, you do so with fossil fuel. If you are going to blend, let's say, alcohol-to-jet, that must also be done with fossil fuel first. Only then are you allowed to combine them. My opinion is: why does it have to be in that order? Why aren't you allowed to mix HEFA with alcohol-to-jet and then blend it? That is much* ***easier in practice****. In fact, we should actually allow you to simply store different types of SAF, pure SAF, mixed together. [...] And that hasn't really been looked into yet. Research has only been done on this once, and the conclusion was: 'Yes, it indeed* ***doesn't matter*** *whether you do A + B and C + B, yeah, whatever. Chemically speaking, it doesn't matter'."*

Although it was noted previously in section 6.1 that SKA-type fuels are more likely to achieve higher blend ratios, this is not entirely true: in the long term, SPK-type fuels should not simply be disregarded. As OEM-2 describes above, SAK is an SBC in development which may unlock more blending possibilities in the future. By blending SAK with an SPK-type fuel, such a fully-synthetic fuel could still comply with all fuel properties. In order to allow such changes, however, there are two requirements. First, SAK would need to be certified under ASTM standard D7566. Second, blending between SBCs would need to be permitted, as this is currently not possible and "hasn't really been looked into yet." (FS-2) Because both requirements could take quite some time to be researched and approved, this could be a drop-in solution for the long-term next to SKA-type fuels.

> **EX-3:** *"In any case, I think that what we will eventually end up with is a* ***combination of many different technologies****, because we won't get there with just HEFA, we won't get there with just FT, and we won't get there with just ATJ. I think we need* ***everything****. [...] I think that — also depending on the* ***raw materials*** *— we will eventually end up with, for example, 'FT is most suitable for producing this,' 'ATJ is more suitable for producing that,' and depending on where which raw materials are available, that some technologies are more logical. For example, in Sweden, they will probably do much more with an FT or an ATJ than with a HEFA, simply because they have a huge amount of forestry."*

> **AIR-1:** *"I don't think one is more successful than the other. We now have HEFA available on a large scale, so that is simply a very important one to blend in ourselves in the coming years, but we also know that those feedstocks are* ***limited****, so that target of 70% SAF in Europe by 2050 — well, we aren't going to achieve that with used cooking oil alone — so we just know that we need both: e-SAF and HEFA, and bio-SAF in general.* ***So it will be a combination of both.****"*

> **FS-1:** *"I think generally it will be* ***both****, or the combination. I think it is a fact that* ***all solutions are needed*** *to mitigate all these climate issues and also the aviation industry targets towards net zero and so on. So from that perspective, I think that* ***all these routes [are needed]****."*

Finally, some participants also noted that reaching EU SAF mandates requires the co-existence of multiple SBC supplies. While in section 6.2 it was noted that HEFA would slowly transition into ATJ and FT, this may only hold true to some extent. ATJ, CHJ, and FT may become more dominant pathways in the SAF industry, but this does not mean that HEFA-SAF will be entirely replaced. As EX-3 also notes, Sweden may find more success using FT- and ATJ-type fuels due to its availability of forestry, but that may not hold true for e.g. Spain. In that sense, provided all pathways have attained a high enough TRL to be used at a competitive price, HEFA-SPK, ATJ, CHJ, FT, and e-SAF could all complement each other depending on the locally available feedstock. In Figure 6.2 below, a projection of SAF capacity and demand in the EU is provided by Warnaar et al. (2026), which estimates a gap between demand and supply by 2035, which would mainly need to be closed by upscaling of other SAF pathways.

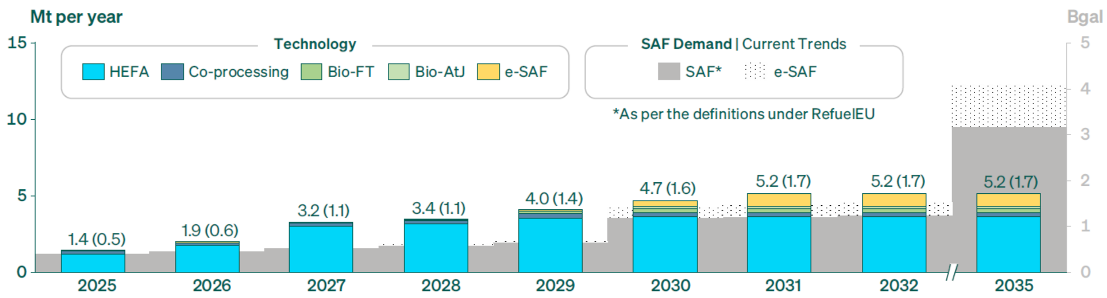


Figure 6.2: SAF capacity and demand in the EU, taken from Warnaar et al. (2026)

7 Strategic Measures

Having established the barriers for sustainable aviation fuel (SAF) - also across different synthetic blending components (SBCs) - this chapter aims to identify measures to overcome these challenges to enable further SAF adoption, effectively answering RQ3. First, types of strategic measures are identified in section 7.1. Thereafter, these types of measures are linked to the challenges using the influencing conditions (ICs) identified for each challenge in section 7.2. Finally, stakeholders are mapped along the participation continuum in section 7.3 for each measure-challenge pair based on their required participation.

7.1. Measure identification

The measures that are induced from textual data are sourced primarily from question 8 in the interview protocol as provided in Appendix C. A summary of types of measures is provided in Table 7.1 below. In the following sections, each type of measure is briefly discussed.

Table 7.1: Rate of occurrence of codes grouped by measure

	Interview														
Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Sum**
mandates and regulations	5	4	1	2	4	5	2		1	7	1	2	9	2	45
incentives and subsidies	2	5	10	3	4	1	1	3		3			4	2	38
technology development				1	3			4	1	3		2		4	18
raising public awareness	2			5			1	1						3	12
knowledge building and sharing	1					3	1	1	1				1		8
networking								2		2				2	6
designated infrastructure	2					1		1	1						5
book-and-claim				2		1						1		1	5
capital investments								2					1	1	4
dedicated SAF allocation	1				2										3
risk coverage			2		1										3
clear governance structure	1														1

Mandates and regulations

Mandates and regulations, as evident from Table 7.1, are among some of the most discussed topics for measures to combat identified barriers, applicable to many of the influencing conditions. Mandates and regulations are noted to play a key role in the SAF industry in general, which is further emphasised by OEM-2 below.

> **OEM-2:** *"It will eventually come down to **policy and regulatory framework supporting SAF introduction** because we can have all the technical stuff in place. Our engines, airframes, they might all be ready to accommodate even the non-drop-in and other great versions of it. Let alone drop-in, we might be ready technologically, right? Airlines might want it and etc., but if the price is not right, it will not happen. **If the regulatory framework is not correctly implemented**; for example, mandates, but how much mandate? Too much mandate will be disruptive for the industry as well, so..."*

With this introduction in place, different participants note a variety of challenges which mandates and regulations can tackle. One of these regards surpassing the 50% blend limit, as evident by statements from EX-3, FS-1, and FS-2 below.

> **EX-3:** *"We need to move more towards a **fit-for-purpose fuel** and not cling to a **maximum percentage**, but rather that if you can simply demonstrate that your fuel meets all the requirements — regardless of what it is produced from, with what technology, and whatever — if it passes all the necessary checks in all the required tests, then we should simply be able to use it."*

> **FS-1:** *"A more concrete or hands-on solution would be this aromatics content **limitation removal**, or at least **relaxation**. So that would be something helping a lot in the long run."*

> **FS-2:** *"Plus, and that is perhaps the second part of the answer, which is also being looked at, is allowing the mixing of multiple types of SAF. [...] So, **allowing multi-blends** where you combine multiple annexes, is simply a very easy way to still get above that 50%. Plus **allowing 100% of individual annexes** that are already good enough in terms of fuel composition. That is the low-hanging fruit."*

Although blending is not yet possible beyond 50%, EX-3 and FS-2 above note that regulations should already allow for SAF blending up to 100%, should they meet all of the requirements in terms of fuel composition, something which may be possible for aromatic-type SBCs such as alcohol-to-jet synthetic aromatic kerosene (ATJ-SKA), Fischer-Tropsch synthetic aromatic kerosene (FT-SKA), and catalytic hydrothermolysis jet (CHJ). This can be further supported through additional regulations supporting the blending between multiple SBCs (FS-2) as well as the relaxation or removal of the aromatic content limitation (FS-1). Additionally, other high-aromatic fuels such as synthetic aromatic kerosene (SAK) can be pursued. However, as EX-3 further comments, "the issue currently does not lie in blend limits for meeting ReFuelEU's objectives." Rather, price and production capacity tend to be more emphasised as the core problems to future uptake of SAF, which are further elaborated by AIR-1 and OEM-1 below.

> **AIR-1:** *"I think it is important that ReFuelEU is **not tinkered with**. Of course, there are airlines calling for a relaxation of the blending obligation, but that is the last thing we should do. As far as I am concerned, we should tighten it, but the most important thing is that there is **stable policy** so that all players in the industry know what to expect."*

> **OEM-1:** *"We could help the innovative processes to compete on the market by being **less prescriptive, less constraining** with all the precautions we have, even at 10% in a fast-track process that would allow small producers to sell their product even at low blend ratio. **We help the ecosystem.**"*

As AIR-1 notes, policy stability is essential to future developments in the SAF ecosystem. With price volatility previously noted as one of the major challenges, policy stability can help stabilize price levels and create certainty on the market for all actors. This was also previously noted by OEM-2 in the introduction: ”if the regulatory framework is not correctly implemented, [...] if the price is not right, it will not happen.” This also connects to OEM-1’s statement. By being less prescriptive in terms of mandates and regulations, the EU could create a more favourable investor climate in the European Union (EU) to support SAF producers and increase production capacity. For example, Renewable Energy Directive (RED) III could be made more flexible to allow more feedstock to be used for SAF production, approval processes could be accelerated in collaboration with the EU SAF Clearing House, and price instabilities could be better covered through liability contracts and Contracts for Difference (CfD). Another solution would be to improve SAF deliveries in the EU, made evident by statements from INF-1, AIR-1, and AIR-2 that propose changes in legislation to combat these challenges.

> **INF-1:** *”We need to just **accept how the banking system works** and just accept that what goes in comes out somewhere. So if you let SAF enter the banking system, that SAF contributes to sustainability goals anyway. So the proposition is to simply **abandon the requirement** that it physically arrives at the party that purchased it.”*

> **AIR-1:** *”Primarily **a change in legislation or regulations [is needed]**, because the molecules of SAF must be traceable. [...] A change simply needs to take place there to perhaps make things a bit more **flexible**. [...] If we make that supply chain more efficient by having it blended in the CEPS pipeline? Yes, that naturally also has a beneficial effect on the price because it is much more efficient.”*

> **AIR-2:** *”I think I would say extra **flexibility** regarding SAF deliveries. [...] We have to focus on the mechanism that is pushing an incentive, which is through EU-ETS, but it’s not very flexible because they want to keep traceability of SAF to a certain level.”*

As previously explained, the EU Emission Trading System (ETS) does not allow airlines to transport SAF batches through the Central European Pipelines System (CEPS) due to a loss of traceability. Because of this, there is a loss of efficiency in the operational structure of the SAF industry. Therefore, AIR-1 and AIR-2 propose to introduce a degree of flexibility that permits transport through the CEPS, or, as INF-1 notes, to fully abandon the ETS requirement of physical proof of delivery. Furthermore, the process of translating proof-of-delivers to EU ETS claim forms, noted to be arduous, should also be streamlined. This, however, addresses only one disparity among existing regulations. To further resolve complications, SAF industry norms and processes should be translated into ReFuelEU aviation legislation, which can then be extended globally while simultaneously dissolving any national ambitions. If such measures could be undertaken, the only challenge remains in the final part of the supply chain: limited demand.

> **EX-1:** *”First and foremost is to make sure that the **demand goes up by strong regulation**, an insurance that pushes airlines to purchase more SAF. That’s very clearly step one. [...] I think the regulatory aspect to drive demand will lead the market to need to think about how we are going to get those higher blend percentages.”*

> **AIR-2:** *”We want to communicate on sustainability, on SAF and what we do. It is **extremely difficult** because we have to comply with a lot of different rules, some that are logical, some that we’re thinking, ’okay, these are just **hindering** us to communicate with our passenger’.”*

As EX-1 notes, demand by airlines could be further driven by regulations as a means to incentivize SAF production. AIR-2 notes that this can be further extended to limited demand by passengers due to constraints imposed by communication laws, relaxation of which may enable future knowledge-building processes.

Incentives and subsidies

To add onto OEM-2's introductory statement regarding mandates and regulations supporting SAF uptake in the previous section, the excerpt below further extends this concept to incentives and subsidies.

> **OEM-2:** *"Government **incentives** and mandates are very much needed, I think, to cross that threshold towards commercial production. [...] Mandates as well as incentives that kind of **bridge that [price] gap** are needed. We thought that they would be needed in a very short term to get the industry going. But at least to me, it looks like **those kind of measures will be needed for a long time** if we want SAF to pick up."*

OEM-2's statement is exemplary of what can frequently be found in other interview findings: government incentives and subsidies are closely intertwined with imposed mandates and regulations. Technologies such as SAF cannot be solely driven by either incentives or mandates, but require both components for successful uptake in the aviation industry. Thus, incentives and subsidies are also applicable to many of the influencing conditions. As opposed to mandates and regulations, however, incentives and subsidies are more specifically focused on bridging the price gap between SAF and conventional aviation fuel (CAF). To do so, one possible avenue concerns subsidizing uptake among airlines.

> **AIR-1:** *"Simultaneously, you also see with the new Emission Trading System (ETS) that airlines will have to pay more for their emission rights; well, that makes the business case **more attractive**. [...] What is possible, however, is to **encourage that voluntary demand** above ReFuelEU at the national level, and perhaps the government will introduce measures to regulate this, through subsidies or other means. [...] What I believe Schiphol already did in 2015 is a sort of SAF incentive fund, where airlines can receive a kind of subsidy to bridge the price gap between fossil kerosene and SAF."*

> **AIR-2:** *"Currently, what we have is when you blend SAF, you have to pay less ETS and you can also get some ETS rights back with what they call the FEETS incentive. These are limited. And we know for a fact that for an airline, if you do have incentives and if you get a financial reward specifically that can help with your costs, we can blend more SAF."*

> **EX-3:** *"I think that it is again very strongly linked to that financial aspect in the first place, but what is also being investigated now, for example, is whether the money raised through the ETS — the Emissions Trading System — can be fed back into the aviation sector for, say, SAF production. I think that would be a **good financial boost**."*

> **FS-2:** *"Perhaps you could also combine it [ReFuelEU] with the American model. Where there is also **a reward for performing better than certain obligations**. To my knowledge, that does not currently exist in Europe. So that could be something to improve it further."*

As AIR-1, AIR-2, EX-3, and FS-2 discuss above, the EU ETS system currently in place acts as a subsidizing mechanism which helps narrow the price gap and incentivise airlines to purchase SAF. Airlines could, however, be further incentivised by e.g. supplementary subsidy schemes implemented either on a regional level (FS-2) or a national level (AIR-1), or to allocate more of the funding raised by EU ETS to SAF developments (EX-3). Of course, monetary funds in the form of incentives and subsidies could also be shifted to upscaling production for low Technology Readiness Level (TRL)-type SBCs such as ATJ, CHJ, FT, and e-SAF. This concept is explored below.

> **INST-1:** *"Out of necessity, there could actually be an **incentive** for those other [advanced raw material] flows. There is 90 million available from the Climate Fund for alcohol-to-jet as new technologies to produce alcohol, which in turn can be made from all kinds of raw materials."*

> **EX-3:** *"Due to that increased NATO spending standard, an opportunity arises there to* ***stimulate technology for energy production*** *of, for instance, more synthetic fuels, so from CO_2 in the air and water."*

Whereas efforts are underway to scale production capacity of SAF in general, such efforts are further intensified for underdeveloped SBCs. As INST-1 notes, the pool of available resources for hydroprocessed esters and fatty acids synthetic paraffinic kerosene (HEFA-SPK) is estimated to run dry in a few years. Out of necessity, then, the development and stimulation of other pathways such as ATJ (INST-1) and e-SAF (EX-3), which are less technologically mature, are subsidized in order to scale up their production capacity and compete with HEFA-SPK.

Technology development

Enabled through mandates and regulations or incentives and subsidies, further development of multi-SBC blending, low-TRL SBCs, and fully-synthetic aromatic-type SBCs has already been previously discussed in the sections above and is currently being developed by authoritative bodies. Such measures are examples of means to tackle barriers which originate from a lack of technological maturity (IC1). One type of technology development has not yet been touched upon, however, and is further elaborated upon by TRO-1 below.

> **TRO-1:** *"On a bigger scale, I think* ***digitalization*** *and* ***automation*** *is a huge issue. So with certification, that's another part of it. So what I mean by that is that a lot of the documentation having to do with this, with the certification process, is still* ***manual****. [...] There's no automated way of doing it. So a lot of focus in technology in the industry is going towards* ***modelling****, like 3D modelling and modelling testing scenarios and predictive maintenance. And I think that, like, leaps in that technology will help with the adoption of new technology in future. [...] And then on top of that,* ***streamlining the certification process****, digitalizing would help."*

In the context of administrative burdens, TRO-1 argues for increased digitalization and automation to streamline the certification process. Furthermore, improved modelling and testing techniques could help in reducing blending uncertainties during SAF production, should sufficient knowledge regarding blending dynamics be gathered.

Raising public awareness

A measure which is more detached from policy-making and subsidies concerns raising public awareness, most specifically designated for barriers which are caused by socio-cultural aspects (IC8). As argued previously in chapter 5, the general "public" here should not solely concern the passengers on commercial airlines, but all stakeholders in the SAF ecosystem. EX-2 shares their experience in the following excerpt regarding this topic.

> **EX-2:** *"I definitely think that* ***raising awareness*** *is a big part of the work that we have to do because when I started working with airlines, I really felt like the airlines who didn't know anything about SAF, they were like,* ***'but why would we buy a fuel that is more expensive?'*** *And then as soon as they had some demand from their customers, their clients, or passengers, they're like, 'okay, we need to look into it. But if we buy this fuel, we want to fly on the fuel.' [...]* ***And now, most of the airlines know how it works.*** *But still, four years ago, airlines were like, 'oh, if we buy the SAF, we want the molecules on our aircraft.' Sure, but do you know your supply chain or how it works?"*

Although airlines are closely involved in developments of the SAF ecosystem, EX-2 notes that they were previously not well-informed on what the technology meant or how it could be adopted, despite the knowledge already existing. Only by raising public awareness could information be more properly conveyed and could stakeholders be more actively involved. While the problem in the narrative sketched above is resolved, similar cases are still at large, illustrated using the following statements.

> **EX-2:** *"The refinery consortium / lobby is not very happy about it [cleaner fuels] because they say 'oh, it's going to be super expensive and then we're going to lose jobs and we're going to close refineries'. I think* ***more and more data show that it's not the case*** *and it's definitely something we need to investigate."*

> **EX-2:** *"We also still hide behind the fact that there is a lot of* ***uncertainty****, you know, contrails and so on. But I think there is enough research that is being done to show that* ***we know enough to start implementing some measures.*** *And then it's really [about]* ***awareness****."*

> **TRO-1:** *"Gathering data on all these companies is difficult, but then also getting, creating* ***awareness*** *about what all these companies do and how much expertise we actually have in the country is a monumental task."*

> **AIR-2:** *"We know that for some passengers, it's important to be able to contribute in some way in decarbonizing their journey. And we think that SAF is the most concrete and the most easy way for a passenger to do so. So if people were* ***more aware*** *of it, understand the product, then we would maybe see* ***more SAF sells****, which would give us a signal to also share with fuel provider to say, 'there is an interest. Can we do more?' [...] We do need to have this* ***awareness*** *because it's not something that people have and you cannot blame them for that because* ***it's just not a common topic to discuss at the dinner table.****"*

In statements from EX-2, TRO-1, and AIR-2, raising awareness has been shown to be able to promote uptake of SAF under different circumstances. In some cases, it may help alleviate scepticism and uncertainties amongst stakeholders that actively prevent collaboration and coordination processes (EX-2). In other cases, raising awareness about the potential networks accessible to stakeholders can help further stimulate those same processes (TRO-1). Finally, as noted by EX-2, if the public is made more aware of what SAF is and understands it as a product, they are also more willing to voluntarily invest in SAF, something which could be accomplished through accessible mediums of communication such as information guides at airports or in-flight educational videos. Thus, raising awareness among stakeholders in the SAF ecosystem may be crucial to the success of SAF.

Knowledge building and sharing

Knowledge building and sharing, as a means of resolving a lack of knowledge and awareness concerning a product's technology or market aspects (IC1, IC2), shares common themes with raising public awareness. However, the former distinguishes itself from the latter by acknowledging that raising awareness can only be enabled if sufficient knowledge is built. Furthermore, "knowledge sharing" refers to the extent of making this knowledge accessible to others rather than disseminating such information to a specific audience. OEM-1 further elaborates on this concept in the statement below.

> **OEM-1:** *"Building this knowledge has to be* ***shared*** *among all the community. Otherwise, it's just one OEM has the knowledge and you say, okay, I'm okay with this relaxed specification because it will help this producer. It's pointless because ASTM is* ***working by consensus*** *and everyone has to be at the* ***minimum knowledge has to be shared*** *so that any evolution of the spec can be easily accepted. So this research probably has to be done in an academic world and published* ***openly****. That's what we are advocating and pushing."*

Noting American Society for Testing and Materials (ASTM)'s processes as a primary example, its industry norms are developed by consensus among all ecosystem stakeholders - otherwise, it would not be adopted as an industry norm. To reach this level of consensus, OEM-1 explains how sufficient knowledge needs to be built and shared among the entire community, and how there is a continued need to do so for future developments of SAF. Although EX-2 previously argued that "we know enough", there are still a few gaps in knowledge which have not been addressed. This is further argued using the statements by FS-1 and OEM-1 below.

> **FS-1:** *"I would say that it should be then investigated to what level the minimum aromatics could be decreased to keep these operations very efficient and so on. [...] I think a more feasible way would be that it should also be investigated, if* ***min. 8% aromatics is really required****, or could it be something lower, like 4% or 2%, or what could it be? The* ***industry should seek for variety of options*** *and flexibility to enable higher SAF content in the future."*

> **OEM-1:** *"As we run into the 50 percent limit or as we want to enable new pathways to be more open and easier to come to market, we need to go back to these fundamentals and this has to be supported by public funding because it's quite a big effort and also giving a public funding would give coordination.* ***If we do one OEM with one lab, there is no point.*** *[...] So having a big effort and maybe* ***coordinated*** *by EASA or coordinated by the European Clean House. [...] From 30% to 50%, then beyond 50%, up to 100% drop-in, and up to 100% non-drop-in, fully paraffinic fuels.* ***It's a full picture, and this knowledge actually is lacking today.*** *[...] We want to go more efficient, faster, and beyond 50%, but we realise* ***not everybody is comfortable****. We lack knowledge, actually. So building this knowledge should be the first priority, and it will enable many of these SAF ramp up indirectly."*

Networking

Guiding an entire industry through a technological transition requires cooperation and coordination, which can be achieved through networking between partners. Such a measure helps combat limited coordination, which can be related to competition (IC6), macro-economic and strategic aspects (IC7), and socio-cultural aspects (IC8). TRO-1 offers an initial statement on this topic below.

> **TRO-1:** *"A lot of people don't know which companies to go to or who to talk to about things in general. And things, I mean, like technology, it could be certification, like* ***who would you go to, you know?*** *So a lot of the time what we try to do is we try to make it as simple as possible to* ***connect*** *or to* ***link up*** *with other people."*

Although this concept is quite broad, FS-2 and AIR-2 respectively provide further arguments for networking as a viable means to combat challenges specific to the SAF industry. These are provided below.

> **FS-2:** *"We, on the other hand, have a very large* ***network*** *of corporates. Think of Microsoft or the PBCs of this world, which do a lot of business travel and are very keen to green their emissions. [...] Of course, they themselves do not have the ability to purchase SAF as fuel, because they do nothing with fuel. They just buy plane tickets. What we do is ensure that they pay the premium for biofuel, bio-kerosene, compared to fossil kerosene, and we ensure that that quantity subsequently replaces that amount of fossil fuel somewhere in the world. That is essentially the game we play; so in that way,* ***we link the corporate industry to a physical fuel industry.****"*

> **AIR-2:** *"If we would improve on that [traceability] and make it more flexible, I think it would also be easier for us to blend more [...] and to make it* ***accessible more broadly****, I would say, in Europe and for us in the Netherlands, because now we're a bit limited on where we can do that. And doing it with* ***different actors****, I think, would also unlock something."*

Designated infrastructure

An upside to SAF – as previously outlined in Chapter 5 – is that it can be transported through the same infrastructure as that of CAF. As a result, however, this does not promote higher blend ratios. The code "designated infrastructure" refers to the idea of participants initiating an infrastructure separate from that of CAF, which also includes separate rules and regulations. An influencing condition that plays a primary role in this discussion is additional financial resources (IC5). EX-1 and FS-1 elaborate on this below.

> **EX-1:** *"The current system, which I explained was having everything in one bucket and then everything coming out of that same bucket, it **doesn't initiate any high blend percentages**, right? There's no reason to do high blends because it's just going to go in the bucket anyway. So, you need to have an **alternative supply chain** to be able to make use of any kind of high blend SAF."*

> **FS-1:** *"Maybe the question is that the new fuels, which means SAFs, should now mimic the conventional jet fuel as much as possible. But what if they could be a little bit **different**, wider or a bit different range of molecules and they don't need to fulfil all these most stringent or same parameters? [...] So there comes these kind of many things to consider in the SAF blending process, and that can cause them limitations (either causes now or in future). But what if we could **more openly define** and proof via testing that how would the wider range SAF fuel look like and not strictly compare to how has the fuel been before?"*

> **OEM-1:** *"It's [Jet X] among the ways to get to 100%, it's one of the possible ones, but we see it as a much more longer term, because of what we have done as research to dig onto these solutions. It's true that you have to look at the fuel system and the engines. Are they compatible with this? [...] It's probably a next generation aircraft that will be more suited to these kind of modifications because they are not so easy modifications to make on in-service aircraft. You have to look at the **global ecosystem**."*

Book-and-claim

Book-and-claim is an accounting principle which introduces more flexibility in SAF supply methodologies, specifically with regards to airlines who wish to make claims under the EU ETS. Under this model, a consumer "books" a certain amount of SAF for a provided cost, after which they can "claim" the corresponding emission reduction certificates. However, the actual SAF is not physically received by the consumer but rather allocated to a nearby airport. In this way, airlines could make claims under the EU ETS even if SAF is not physically supplied to their local airport. Reference to book-and-claim is further provided by EX-2, OEM-1, FS-3, and AIR-2 below.

> **EX-2:** *"I think it could be really interesting for the EU to have a sort of European **book-and-claim** mechanism or something to make sure that we don't **penalize** the smaller airports that are not well connected to a SAF blending facility or SAF production facility, because they will see the increase in SAF logistics increasing while it won't be such a big increase for other big airports connected to pipelines."*

> **OEM-1:** *"On the other side is the **book and claim**. [...] If you have this, these questions will go far in the future. We have time. It both go together to buy us time to make this properly on the technical side, if you manage to **relax the blending limit** through book and claim, then it will push it back a few decades to the right and will let us time to do the search and prepare this, right?"*

> **FS-3:** *"And then you could look at another step - which is being talked about a lot at the moment - to **book-and-claim** for solutions. That makes it [ETS claims] more **flexible**, but even so, you don't have a constraint or a problem with something physical."*

> **AIR-2:** *"These two texts [ReFuelEU aviation and EU ETS] were not created by the same group of people. [...] It's why if you see a lot of discussions that are going on at the moment and have been going on before, is this discussion about what is feasible in term of **book-and-claim** and **flexibility** mechanism, because it's not clear at the moment."*

Capital investments

Separate from incentives and subsidies is another code defined as ”capital investments”. While capital investments may contribute towards achieving positive change for private firms, such a measure is not directly aimed at private firms but rather at a positive structural change for an entire ecosystem. Thus, such a measure may be directed towards tackling multiple influencing conditions. The excerpts from TRO-1 and OEM-2 elaborate further on this below.

> **TRO-1:** *”More broadly, at a European level, I think there’s a* ***structural*** *question about how prepared the continent is to produce these kinds of fuels at scale and cost-competitively. Over the past few decades, a lot of production capacity moved elsewhere for cost reasons, and that has* ***knock-on effects*** *when you try to ramp it back up... workforce capacity being one of them. My own view is that there’s more room to focus on* ***lowering energy costs*** *and* ***investing in automation*** *in Europe as a way to make production more viable.”*

> **OEM-2:** *”From my perspective, anything that houses commercialization, production of fuel, say, against other sectors, reducing the price gap, reaching towards price parity with conventional fuel, etc, [...] the* ***investment*** *and the regulatory and policy framework that is supportive of the advancement of SAF introduction, that’s to me the most important piece. I would like to see those change in a* ***more supportive*** *manner.”*

Dedicated SAF allocation

Participants frequently note a limited supply of SAF which still yields limited impact. A means to increase the impact of the little SAF that is available to be allocated to dedicated flights for which SAF can make the most impact. EX-1 and EX-3 elaborate on this principle below.

> **EX-1:** *“On the topic of contrails and non-CO_2 contrail formation, if you can see that lower aromatic fuels or high blend SAFs have a* ***lower contrail impact****, then you want to use this SAF on flights that would potentially form a contrail. This is about 5 to 10% of flights over the North Atlantic, which means you could use your 5 to 10% SAF in 2030 - it’s a 6% mandate - to* ***focus specifically on those flights*** *that are going to form a contrail. But to do that, you need to have high blends of SAF.”*

> **EX-3:** *“Studies are also being conducted for the question: ‘Okay, you currently have a certain amount of SAF, is it better to apply a very small amount across various flights, or a large amount in a single flight?’ This is also based on other academic works that have looked into this. The answer from our study was that it was* ***better to have a higher blend in fewer flights than a low blend in many****. [...] If you use 6% SAF in 100% of the flights, that leads to a certain climate gain in a specific climate metric. But if you use a 50% blend on 12% of the flights - so the total amount remains the same but is distributed differently - then you have a* ***higher climate gain****.”*

To summarize above, by allocating higher blends of SAF to fewer flights for the same limited amount of SAF currently available, a higher impact can be yielded. Specifically, EX-1 and EX-3 both note that flights which are likely to form contrails should be targeted for the most significant impact. By such dedicated SAF allocation strategies, the effect of SAF can be more discernible in the early stages of SAF development.

Risk coverage

A lack of certainty in the SAF industry due to unstable policies comes paired with many risks for the various stakeholders in the SAF ecosystem. To lower these risks and combat fluctuations due to concerning limited knowledge of the market (IC2) alongside unprompted accidents and events (IC9), INST-1 and EX-3 elaborate on one example of risk coverage through a Contract for Difference (CfD) below.

> **INST-1:** *"The sector is also working on instruments such as auctions and, for example, government support in a* ***Contract for Difference (CfD)*** *to support, stimulate, or* ***cover risks*** *in contracts between buyers and producers. [...] What is crucial is ways in which governments or financing agencies can commercially cover part of those price risks or price differences to* ***eliminate the uncertainties****, because the sector has limited options to take on those financial risks when price developments are still* ***uncertain****."*

> **EX-3:** *"I think it's similar to what they do in the UK; they have a system there where you have a* ***price guarantee****. So if the price of your product increases because, for example, energy prices rise, the difference between the agreed price and what you wouldn't be able to achieve is covered by the government. But if your product costs less, that money goes to the government. [...] I think such an agreement would be very helpful. Because now, with incredibly* ***fluctuating*** *prices, airlines are* ***hedging*** *their fuel."*

Clear governance structure

Finally, EX-1 notes a lack of governance, paired with "priority paralysis". To remedy this situation, a clearer governance structure needs to be established, as noted in the excerpt below.

> **EX-1:** *"The aviation sector needs to discuss at the highest level what the* ***governance strategy*** *is for fuel property decision making. Are we going for a 100% SAF within Jet A-1, or are we going for Jet X which would allow more SAF producers to comply but then need to make sure that all aircraft engines are tested? And that should be done, in my perspective, at ICAO level, and if ICAO doesn't want to do it, at a European DG-MOVE aviation level."*

7.2. Coupling of measures to key challenges

The previous analysis of barriers in chapter 5 and chapter 6 is summarised into a list of thirteen key challenges. For each item on this list, types of measures are linked based on the influencing conditions (ICs) identified for each challenge. Because types of measures are overarching, the context changes its meaning: a measure suggested for one challenge may require different actions for another challenge. Thus, each challenge and its underlying cause is shortly discussed in more detail, together with accompanying measures based on the provided responses from interviewees. An overview is provided in Figure 7.1 below.

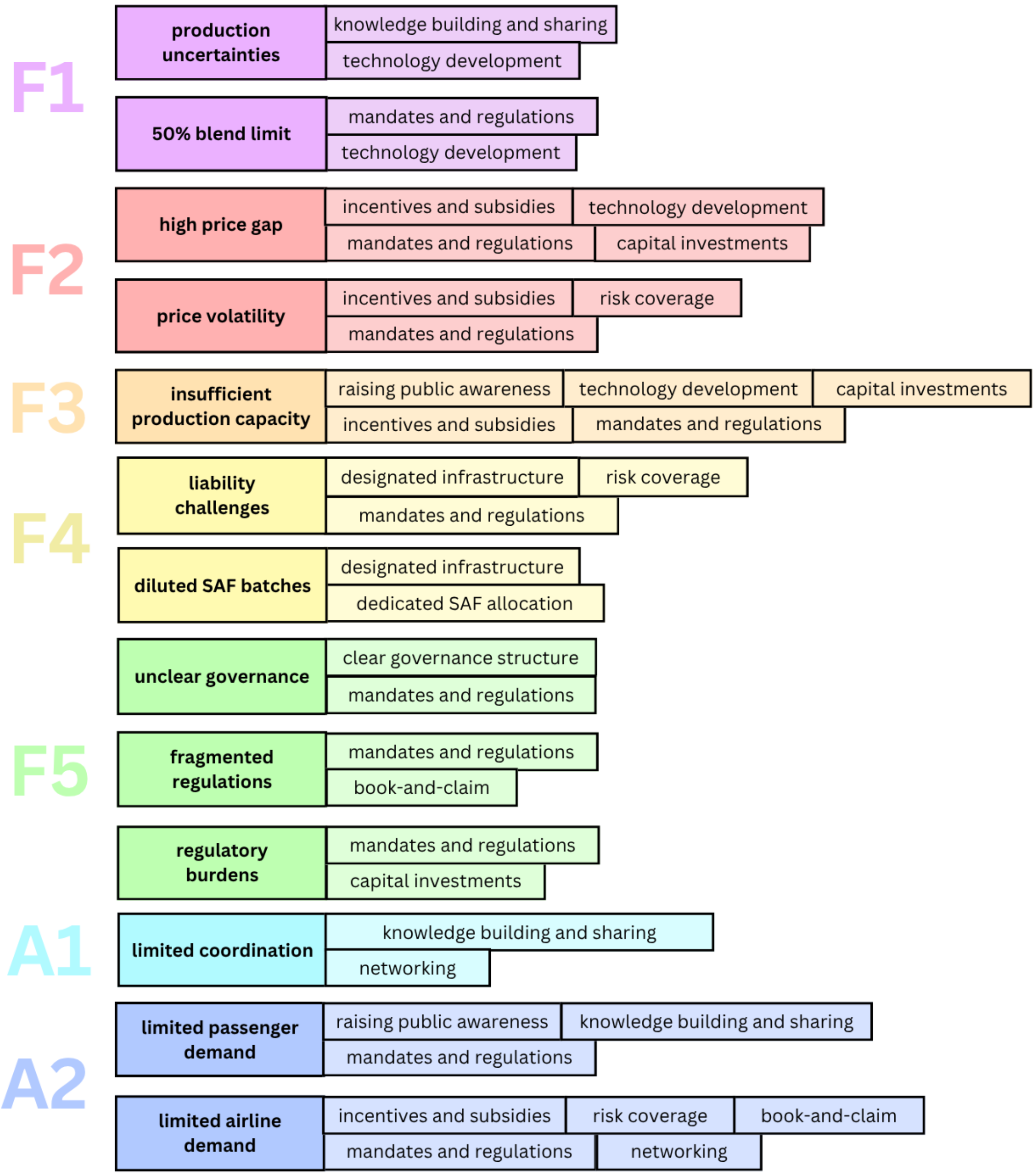


Figure 7.1: Overview of challenges and coupled measures, coloured per TIS (f)actor

F1.1. Production uncertainties

Production uncertainties pertain to the limited knowledge and technology advancements in non-linear blending properties and feedstock variability, which result in blending uncertainties. A means to remedy this could therefore be by pursuing technology developments combined with knowledge building and sharing to mitigate blending uncertainties (F1.1.1).

F1.2. 50% blend limit

All SAF blends are limited to 50% due to constraints imposed by fit-for-fuel properties, with significant changes required to infrastructure for use of low-aromatic fuels. Means to remedy this could be by pursuing technology developments of fully-synthetic fuels such as ATJ-SKA, FT-SKA, and CHJ (F1.2.1) as well as of multi-SBC blending between SPK-type fuels and high-aromatic fuels such as SAK (F1.2.2). Changes to regulations to enable the developments listed in measure F1.2.1 and F1.2.2 should also be implemented alongside the qualification of SAK (F1.2.3).

F2.1. High price gap

The price difference between Jet A-1 and (e-)SAF is too significant to bridge. Means to narrow this price gap could be by increasing public and private funding for further R&D efforts in low-TRL SBCs such as FT, ATJ, and e-SAF to increase cost efficiency (F2.1.1), increasing capital investments in grid expansion to reduce electricity costs, specifically for e-SAF (F2.1.2), increasing capital investments in automation and digitalization (F2.1.3), increasing flexibility in RED III to allow more feedstock to be used for SAF production (F2.1.4), and implementing changes to EU ETS: to either increase SAF allowances through government funding, allocate a higher share of total funds generated to SAF, and/or increase CO_2 and non-CO_2 taxes (F2.1.5).

F2.2. Price volatility

There are significant instabilities in SAF market prices. Means to accommodate these fluctuations are by increasing regulation and mandate efforts to enforce rules and regulations and establish policy certainty (F2.2.1), increasing public spending for SAF development efforts through additional government incentives and subsidies (to signal positive market developments) (F2.2.2), and by covering price instabilities between SAF suppliers and airlines using Contracts for Difference (CfD) (F2.2.3).

F3.1. Insufficient production capacity

There is insufficient bio-SAF and e-SAF production capacity estimated by 2030 as ReFuelEU aviation ramp-up speed surpasses scale-up efforts. Measures to increase production capacity are: increasing private investments for SAF refinery projects through public awareness and trust-building processes (F3.1.1), accelerating technical, regulatory, and sustainability approval processes in collaboration with EU SAF Clearing House (F3.1.2), shifting e-SAF mandates back to accommodate for scale-up efforts (F3.1.3), pursuing development and qualification of methanol-to-jet (MTJ) (F3.1.4), increasing public and private investments for further R&D efforts in low-TRL SBCs such as FT, ATJ, and e-SAF to increase cost efficiency (F3.1.5), increasing capital investments in automation and digitalization (F3.1.6), increasing flexibility in RED III to allow more feedstock to be used for SAF production (F3.1.7), and increasing public spending for SAF development efforts through additional government incentives and subsidies (F3.1.8).

F4.1. Liability challenges

There are tremendous liability challenges for off-spec batches as a result of commingled logistics. To help with these challenges, it may be possible to designate separate infrastructure for storage of SAF (F4.1.1), increase risk coverage by government for off-spec SAF batches (F4.1.2), and implement changes to liability contracts (F4.1.3).

F4.2. Diluted SAF batches

There is a dilution of SAF batches as a result of commingled logistics. To combat this, it is possible to allocate SAF dedicated for high-impact flights (F4.2.1) or designate separate infrastructure for storage of SAF (F4.2.2).

F5.1. Unclear governance

There is no clear authoritative body to guide the SAF industry. Thus, a measure may be to install a decision-making structure with policymakers at a regional (or global) level (F5.1.1) or translate SAF industry norms and processes (ASTM D7566, D1665, D4054, and fast-track qualification) into ReFuelEU aviation legislation and the EU SAF Clearing House (F5.1.2).

F5.2. Fragmented regulations

There are disparities between mandates and regulations at the national, regional, and global (inter-regional) level that create structural inefficiencies in the EU market. Measures to remedy this situation are to introduce a book-and-claim system for the EU SAF supply chain, which enables airlines using CEPS to claim allowances under EU ETS (F5.2.1), to extend EU mandates globally to ascertain a dominant regulation, harmonizing SCS and preventing value leakage (F5.2.2), to maintain current mandated SAF shares, adjust ReFuelEU aviation to implement gradual increases rather than stepwise jumps (F5.2.3), or to dissolve supplementary national ambitions for higher SAF shares, install incentive mechanisms on the regional level for voluntary uptake of SAF above the prescribed minimum (F5.2.4).

F5.3. Regulatory burdens

Local supply chain differences and a lack of standardized processes for making EU ETS claims become an administrative burden for EU airlines. It could prove effective to streamline the process of translating proof-of-deliveries to EU ETS claim forms (F5.3.1) as well as increase capital investments in automation and digitalization (F5.3.2).

A1.1. Limited coordination

There is a conflict of interest between actors concerning trade-offs between sustainability and profits, resulting in limited participation and coordination. Therefore, useful measures may be to establish industry-wide communication platforms for increased knowledge sharing and transparency between stakeholders (A1.1.1) as well as encourage government-led consensus-building engagement processes, dissolving imbalances in power and influence to enable equitable knowledge co-production (A1.1.2).

A2.1. Limited passenger demand

A lack of transparency impairs a passenger's willingness to pay. More focus should be put into increasing public awareness and trust in SAF technology through accessible mediums of communication such as information guides at airports or in-flight educational videos (A2.1.1), relaxing communication laws between airlines and passengers that hinder knowledge-building processes (A2.1.2), stimulating further uptake of SAF CO_2-reduction certificates among private firms (A2.1.3), and establishing industry-wide communication platforms for increased knowledge sharing and transparency between stakeholders (A2.1.4).

A2.2. Limited airline demand

Tight operating margins limit voluntary uptake by commercial airlines. Measures to combat this problem are to implement changes to EU ETS: to either increase SAF allowances through government funding, allocate a higher share of total funds generated to SAF, and/or increase CO_2 and non-CO_2 taxes (A2.2.1), to cover price instabilities between SAF suppliers and airlines using Contracts for Difference (CfD) (A2.2.2), to introduce a book-and-claim system for the EU SAF supply chain, which enables airlines using CEPS to claim allowances under EU ETS (A2.2.3), or to dissolve supplementary national ambitions for higher SAF shares, install incentive mechanisms on the regional level for voluntary uptake of SAF above the prescribed minimum (A2.2.4).

7.3. Stakeholder mapping

To undertake each of the challenges mentioned above, each key stakeholder previously identified is mapped in the participation continuum previously introduced in Figure 4.1. For reference, the overview of all stakeholders and an adapted participation ladder is again provided in Figure 7.2 below. The list of stakeholders remains identical to the one previously mentioned in chapter 4 for the sake of consistency; however, the ladder of participation presented in Figure 7.3 is shortened to only include the top five rungs. This is done because key stakeholders are assumed to take on a minimum level of participation when undertaking the measures that can help alleviate barriers.

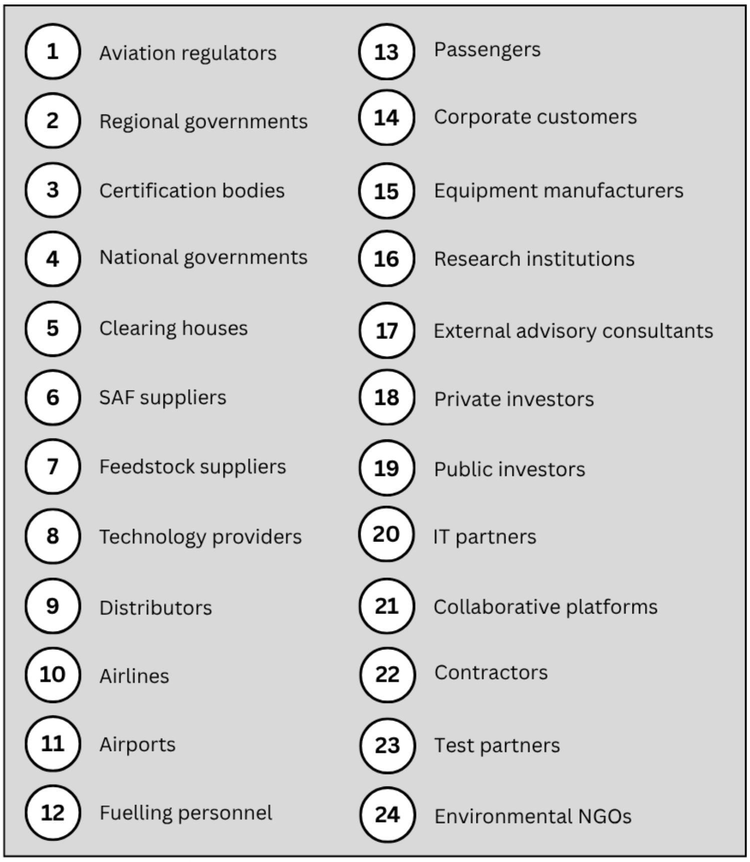


Figure 7.2: Legend used for interpretation of stakeholder mapping diagrams

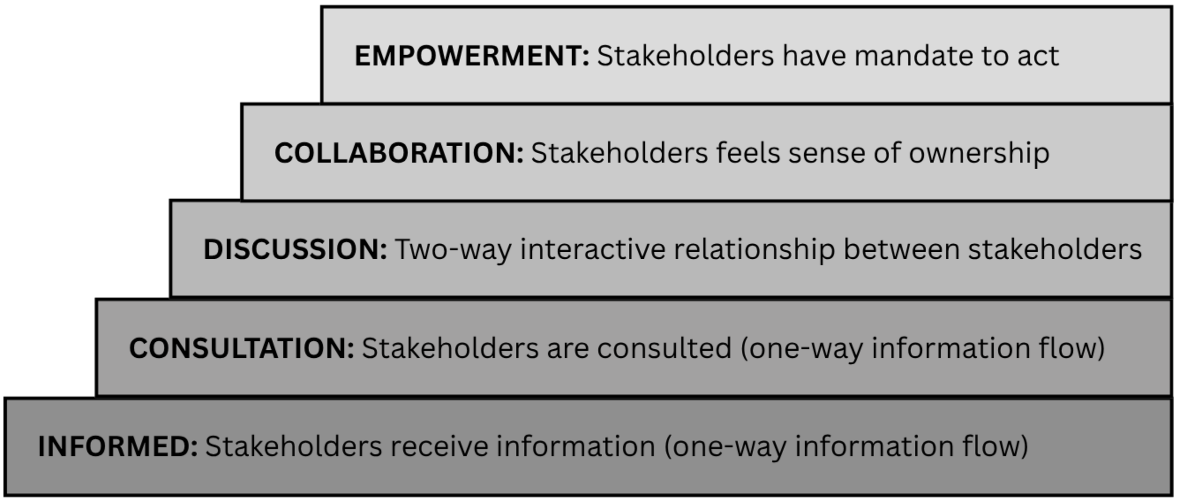
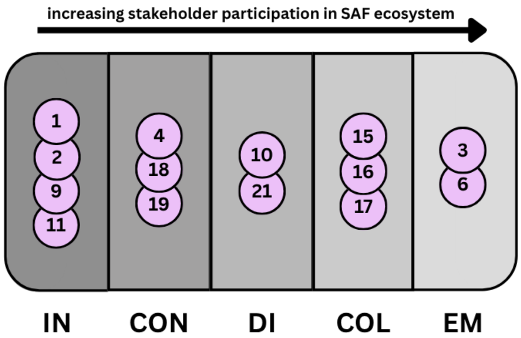
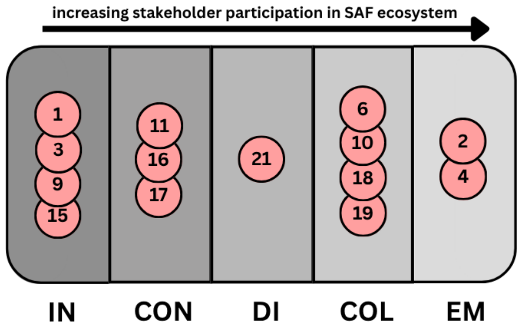


Figure 7.3: Definitions of ladder of participation, taken from Carrera et al. (2021) and adapted to the metrics used in Figure 7.4 and Figure 7.5

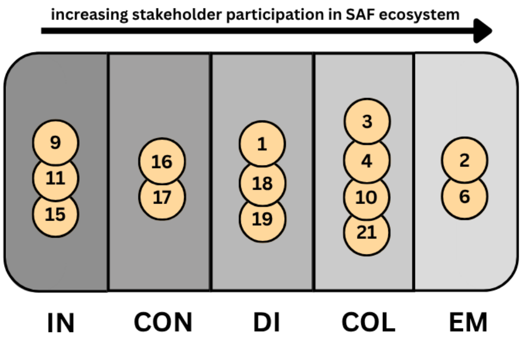
To further elaborate on the stakeholder mapping provided in Figure 7.4 and Figure 7.5 below, seven participation continua are presented, one in each sub-figure. Each sub-figure corresponds to one of seven TIS (f)actors, notated by the different colours that correspond to the respective TIS (f)actor. The grouping per TIS (f)actor is done to visualise how stakeholders may take on different participatory roles when pursuing the measures coupled to these challenges. In each sub-figure, the level of participation is abbreviated to IN (informed), CON (consultation), DI (discussion), COL (collaboration), and EM (empowerment), with an arrow at the top denoting the direction for which stakeholder participation increases.



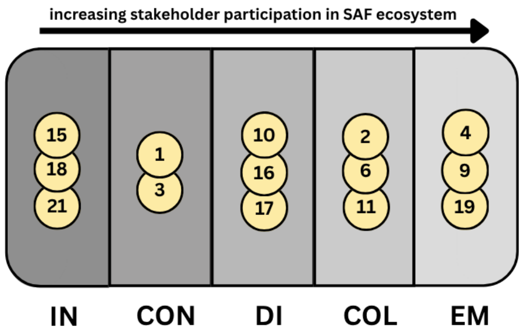
(a) Product performance and quality (F1)



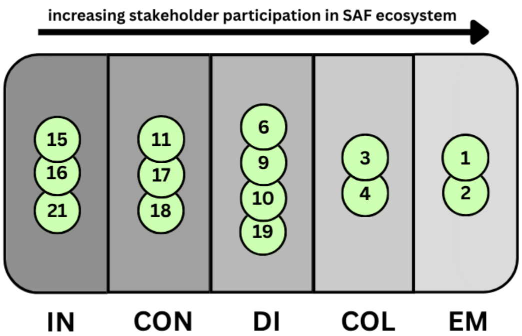
(b) Product price (F2)



(c) Production system (F3)



(d) Complementary infrastructure and services (F4)



(e) Innovation-specific institutions and industry-wide regulations (F5)

Figure 7.4: Mapping of stakeholders in the participation continuum, grouped per TIS factor

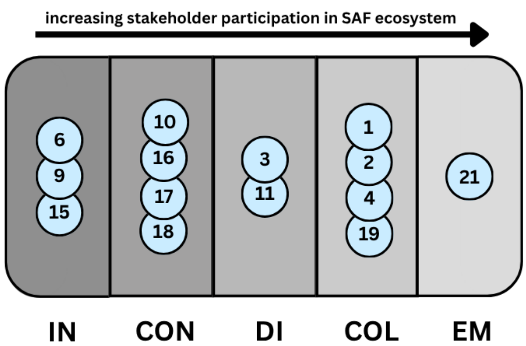
As shown in Figure 7.4a, it is certification bodies (3) and SAF suppliers (6) which should be empowered and take the lead to help remove further production uncertainties as well as blend beyond the 50% blend limit. They are placed here because they are most directly in contact with the production process of SAF and any future industry standards the quality should be held to. Equipment manufacturers (15), research institutions (16), and consultants (17) are depicted as the drivers behind solving these problems, but are not the ones who should take the main responsibility. However, they do hold some sense of ownership, hence their role as collaborators. Airlines (10) and collaborative platforms (21) may further enrich the problem-solving process by joining discussions from a different, holistic perspective. Other regulators and governments (1, 2, 4), distributors (9), airports (11), and investors (18, 19) follow suit, either by remaining informed or being consulted by the other stakeholders.

Next, Figure 7.4b illustrates a situation in which regional (2) and national governments (4) should be more empowered. A large price gap and price volatility can be primarily combatted through incentives and subsidies, mandates and regulations, capital investments, and risk coverage, tools which can be yielded by governmental bodies to signal positive market developments. SAF suppliers (6), airlines (10), and investors (18, 19) can help collaborate on this front as they are the primary stakeholders affected by or affecting the situation, hence their placement. Collaborative platforms (21) join discussions here to ensure a coordinated strategy among the industry. Airports (11), research institutions (16), and external consultants (17) can be consulted for further information and development of technology. The remaining stakeholders (1, 3, 9, 15) - deemed trivial for solving these challenges - simply follow suit by staying informed.

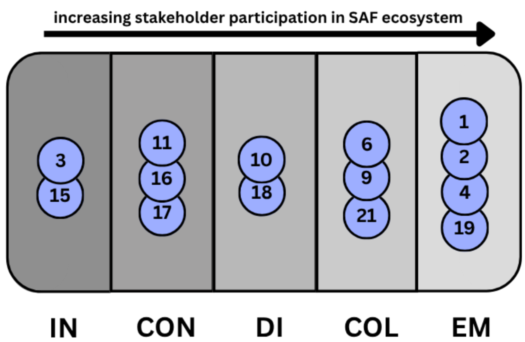
Third, the insufficient production capacity is discussed in Figure 7.4c. In contrast to the role of governmental bodies in F2, this challenge only places regional governments (2) in a role of empowerment. This is because production capacity requires coordination across the EU, together with the SAF suppliers (6) who will produce these quantities. Certification bodies (3), national governments (4), airlines (10), and collaborative platforms (21) contribute by ensuring the regional implementations are distilled on a national level while considering the different needs of all relevant stakeholders. Aviation regulators (1) and investors (18, 19) are then brought into discussions to guide changes to legal and financial instruments in the right direction. The remaining stakeholders (9, 11, 15, 16, 17) either fill a consultative or informative role.

Fourth, challenges concerning current infrastructure and services in Figure 7.4d - albeit less crucial - are spearheaded by national governments (4), distributors (9), and public investors (19). The role of the distributor to operate, maintain, and improve the current infrastructure argues for its importance for this TIS factor. Similarly, increased risk coverage by the government calls for public investors. Furthermore, because this infrastructure is often overseen on a national level, it is national governments that should be empowered. This is followed by collaboration from regional governments (2) alongside SAF suppliers (6) and airports (11) who respectively form the input and output of the infrastructure. Airlines (10), research institutions (16), and external consultants (17) should also join the discussion to stress the impact of proper allocation of high SAF blends and how designated separate infrastructure may help in this front. The remaining stakeholders (1, 3, 15, 18, 21) follow suit, with aviation regulators (1) and certification bodies (3) assuming a consultative role to further guide this process.

Finally, Figure 7.4e displays the allocation of stakeholders to undertake measures that combat regulatory challenges. Unsurprisingly, given the industry's governance, aviation regulators (1) and regional governments (2) assume an empowered role, whereas certification bodies (3) and national governments (4) are collaborators. These stakeholders are also placed here because a majority of challenges can be resolved through making changes to mandates and regulations. The key players in the supply chain, SAF suppliers (6), distributors (9), and airlines (10), should be included in the discussions alongside public investors (19) due to the relevance of capital investments. Because airports (11), external consultants (17), and private investors (18) may further aid in discussions, they take on a consultative role. Meanwhile, the remaining stakeholders (11, 15, 21) stay informed without further influence on the problem space.



(a) Network formation and coordination (A1)



(b) Customers (A2)

Figure 7.5: Mapping of stakeholders in the participation continuum, grouped per TIS actor

First, the level of participation between stakeholders to combat challenges concerning the network formation and coordination among them is shown in Figure 7.5a. In this diagram, collaborative platforms (21) are key to overcoming any coordination challenges by establishing fair (government-led) platforms to share knowledge and increase transparency within the industry. The remaining stakeholders follow in lower rungs of the continuum, dependent on their available means to support these motions. Regulators and governmental bodies (1, 2, 4, 19) take on a collaborator role, followed by certification bodies (3) and airports (11) to join discussions. Thereafter, airlines (10), research institutions (16), external consultants (17), and private investors (18) could be consulted, and finally SAF suppliers (6), distributors (9), and equipment manufacturers (15) simply remain informed.

Second, challenges concerning limited passenger and airline demand, as shown in Figure 7.5b, place regulators and governmental bodies (1, 2, 4, 19) in a role of empowerment. This is because a majority of measures emphasise changes to mandates and regulations, risk coverage, and incentives and subsidies. Because a book-and-claim system may also play a key role in increased airline demand, distributors (9) assume a consultative role alongside SAF suppliers (6) and collaborative platforms (21). The latter stakeholder also may be useful in this context due to measures that relate to raising public awareness, knowledge building and sharing, and networking. Of course, to enforce such changes, airlines (10) and private investors (18) should also be closely involved in discussions. Airports (11), research institutions (16), and external consultants (17) may be consulted for further information, but are otherwise not relevant. This also holds for stakeholders (3, 15), which solely remain informed.

To conclude, different TIS building blocks require different levels of participation among stakeholders dependent on the context of the challenges and coupled measures. For example, Figure 7.4a places certification bodies, SAF suppliers, OEMs, research institutions, and external advisory consultants in roles of empowerment and collaboration to further investigate production uncertainties and the 50% blend limit due to its technical nature. On the other hand, undertaking measures in the context of innovation-specific institutions and industry-wide regulations, as shown in Figure 7.4e, displays regulators, governmental bodies, and certification bodies leading the collaboration, because such measures more heavily emphasise regulatory contexts. Therefore, although not every stakeholder may be equally suitable for overcoming all challenges, every key stakeholder plays some essential role in helping overcome one or more barriers to the introduction of SAF to the aviation industry. Through the mapping of stakeholders for (f)actor-specific challenges, collaboration and coordination processes among stakeholders can be further enhanced.

8 Discussion

Following the findings of the analysis, this chapter explores these results in further detail. In section 8.1, results are compared to existing literature to understand whether they align or diverge. Thereafter, section 8.2 elaborates on the scientific relevance of the findings compared to existing literature. Next, the strengthening of validity and reliability throughout the research process is further discussed in section 8.3. Finally, section 8.4 explores research limitations and how they might affect the findings.

8.1. Interpretation of findings

In this section, the findings of the research are discussed and compared to existing literature. This is first done for the Technological Innovation System (TIS) building blocks, then across synthetic blend components (SBCs), and finally for the formulated strategic measures.

TIS building blocks

With regards to production uncertainties, both feedstock variability and blending uncertainties suggest that there is a production uncertainty when it comes to blending sustainable aviation fuels (SAF), because producers cannot adequately control and predict the properties of the final SAF product. This aligns with existing literature which extensively discusses low ”SAF yields” (Ding et al., 2026; Uddin & Wang, 2025), with the effect of feedstock variability studied in further detail in a case on the use of winter canola for hydro-processed esters and fatty acids (HEFA) production (Bolakhe et al., 2026). Non-linear blending is a less studied discussion, but existing literature also agrees here, noting ”properties of drop-in fuels are not simply additive or superposition, as they are influenced by intricate interactions among the hydrocarbon molecules” (Batool et al., 2025). Further interesting to note is that the topics concerning product performance and quality were mainly discussed by external experts (i.e., EX-1, EX-2, and EX-3 for a total of 19 occurrences). This illustrates how challenges that were more technical in nature are less well understood among those who lack relevant expertise, or are not seen as challenges to begin with. This is especially relevant for SAF suppliers, who barely mention blending uncertainties or feedstock variability (only 1 occurrence by FS-3).

Among all fit-for-purpose properties defined by American Society for Testing and Materials (ASTM) D7566, aromatics were most heavily underlined by participants as the root cause behind the 50% blend limit. This is further emphasised by its potential effect when reduced: future fuels would become considerably cleaner as aromatics are noted to be a major component of local pollution and non-CO_2 emissions (Faber et al., 2022). However, as few participants noted and also is suggested by (ASTM International, 2023), SAF must also have e.g., a freezing point, viscosity, and lubricity that is within specification. Although the effect of these intricacies on the blend limit is unknown, the 50% blend limit is not the largest concern for the time being among participants and literature, which emphasises scaling up production capacity (Ding et al., 2026) and lowering the price (Uddin & Wang, 2025). Nevertheless, the blend wall will become more important over time as blend shares mandated by ReFuelEU aviation increase in the coming years.

In the context of regulations, both literature and findings show that approval processes are notably long. Because of rigorous certification processes, the aerospace sector inherently has a longer innovation duration (5-10 years) compared to some other sectors such as software and ICT (Penner et al., 1999). Furthermore, fragmentation of regulations are prevalent (Ding et al., 2026; Uddin & Wang, 2025; Vishwakarma, 2025), with inter-regional (de Zeeuw & Bekamp, 2025; Reisdorf et al., 2025) and intra-regional conflicts (Ahmad & Xu, 2021) both captured. The only type of fragmentation that the literature fails to elaborate on is on a national level. With the Netherlands aiming for an 8% SAF share beyond what is mandated by ReFuelEU aviation - determined in the Akkoord Duurzame Luchtvaart that was released prior to ReFuelEU aviation (Ministerie van Infrastructuur en Waterstaat, 2019) - a conflict of interest arises in the context of voluntary uptake by airlines. In some cases, literature notes that this directly impacts the health of employees and inhabitants living nearby (Inspectie Leefomgeving en Transport, 2026). What is also interesting to note is the spread of code occurrences related to regulations and institutions. Not only is this TIS factor found to be the largest among all TIS (f)actors, it also covers the largest number of topics. Whereas all other TIS factors contain three codes of which one comprises a significant majority of occurrences, this TIS factor covers six different topics with a much more equal spread of code occurrences. This could imply that regulatory challenges in the SAF industry could be deemed the most complex to tackle due to the wide range of identified topics. However, it may also imply that opinions regarding such challenges may not be as aligned within the SAF industry as much as for other TIS factors, which were comprised of fewer topics and a less equal spread of occurrences.

The knowledge and awareness of environmentally-friendly alternatives for means of transportation by the general public is surprisingly low. In a study on environmental awareness, Boermans et al. (2024) found that younger generations are willing to contribute to the environment but are hampered by a lack of accessible knowledge and understanding. Meanwhile, older generations actively engage in sustainable activities but face challenges related to unclear communication. Thus, the article calls for an increased need for accessible information dissemination, transparent communication, and regulatory measures. This, however, is complicated by the limited means through which communication with passengers is possible, because there are certain restrictions imposed by consumer laws so as not to mislead customers (Verbruggen & Schuijers, 2025). However, public trust in the sector has been previously harmed after deceptive marketing strategies were used to make flights appear more sustainably beneficial through the carbon offsetting mechanism. As a result, airlines incur reputational and financial losses, and trust in such mechanisms deteriorates over time (Sasaki, 2025). This is especially difficult when negative signals from the SAF industry continue to be emitted to the public: the use of passing down barely used and virgin palm oil as Used Cooking Oil (UCO) for SAF (Journalismfund Europe, 2025), the exploitation of Kenyan farmers for the potential production of feedstock (Gros et al., 2026), the ban on Virgin Atlantic's 100% SAF marketing gimmick (Stay Grounded, 2024), or the lawsuit against KLM's series of misleading SAF advertisements (Becker, 2024). Although airlines are the focal point of communication with the general public, it can be argued that the entire industry is responsible for raising awareness and building trust. More interestingly, it was found from interview data that building trust and raising awareness as proposed by the TIS framework is not focused solely on the consumers (or end-users) such as airlines and passengers, but also all other actors inside the SAF ecosystem. When looking at the spread of code occurrences for the customer segment, it can be further noticed that limited voluntary uptake, low willingness to pay, and public perception and trust are almost all mentioned by the same set of interviewees. Thus, all interviewees deem public perception and trust relevant for uptake by airlines and passengers, with further implications that uptake could be increased if public perception and trust are also improved.

SBC comparison

Results regarding price levels compared to Jet A-1 are expected, although feedstock availability (da Silva Gonzales et al., 2026; Uddin & Wang, 2025) was found to be a much more prevalent topic than was found in literature, which in contrast emphasised TRL (Ding et al., 2026; Vishwakarma, 2025). Similar to findings, literature notes HEFA-SAF to currently be the cheapest SAF at approximately $3/gge (gallon gasoline equivalent) (Bhatt et al., 2026), having attained the highest TRL among all pathways (Mariyam et al., 2026; Raihan, 2025) and effectively covering the largest supply of SAF across the globe. With 82% of SAF production relying on HEFA technology, however, gray literature notes that a "HEFA tipping point" is identified in the near future where demand outpaces potential HEFA-SAF production due to limited feedstock availability (Warnaar et al., 2026). These results can also be retraced to the comparative SBC analysis, which envisions HEFA technology slowly transitioning to alcohol-to-jet (ATJ) and Fischer-Tropsch (FT) technology. Surprisingly, although catalytic hydrothermolysis jet (CHJ) shows promising signs in achieving high blend ratios alongside FT-SKA and ATJ-SKA and has achieved similar levels of technological maturity, it has not been mentioned as one of the SAF pathways to be stimulated or help fill the future supply-demand gap. Thus, it may prove useful to further investigate the benefits of CHJ technology in overcoming identified challenges.

Strategic measures

The measures that were formulated in chapter 7 were fully induced from interview responses, which were consequently linked to challenges based on their influencing conditions. However, the legitimacy of these measures or their feasibility has not been approximated at any point, and this was done intentionally. Although none of the measures are contradictory and add up to an acceptable solution space, it is not possible to weigh the viability of one solution against another. Although such tools would help in comparing the difficulty of one barrier over another, a better understanding of the SAF industry's intricacies and connected sectors is necessitated. It requires a great deal of effort and time from policy-makers to establish a single SAF mandate that balances multiple stakeholder needs, which is why any alterations are equally - if not more - difficult to make. However, as can be illustrated by the rate of occurrence of measures mentioned, almost every participant has mentioned some type of policy and fiscal instruments as a means to overcome barriers in the SAF industry, largely placing the responsibility in the shoes of governmental bodies. While they may act as one of the central stakeholders in many challenges, analysis has shown that this is not always the case: at least every stakeholder is assumed to take on a role of empowerment or collaboration once, holding a sense of ownership in resolving issues.

8.2. Scientific contribution to literature

The findings of the research contribute to the literature in three ways.

First, the key challenges facing the SAF industry, together with the strategies to address them, have received limited attention in existing literature as they are notably fragmented and dispersed. By applying the TIS framework to the SAF sector, the research systematically reveals a comprehensive overview of barriers to large-scale SAF adoption, addressing an important gap in SAF literature. Furthermore, by mapping strategies to help overcome these barriers, the research highlights the importance of stakeholder involvement in addressing barriers and facilitating the transition towards large-scale SAF deployment.

Second, the application of the TIS framework in a multi-actor system broadens the perspective on barriers and strategies beyond the level of individual firms. One of the primary findings reveals that building trust and raising awareness should not be directed solely at the consumers (or end-users) such as airlines and passengers, but also at all other actors inside the SAF ecosystem such as fuel suppliers, private investors, and OEMs. Similarly, the strategies developed to help overcome the barriers are not enacted by a single stakeholder, but rather involve collaboration and coordination among stakeholders, with each fulfilling different roles in this process.

Third, the research addresses a point which has not yet been properly emphasised in existing SAF literature: quantity precedes quality. The existing system in place for the use of SAF cannot appropriately handle high SAF blends, both because mandated blending shares are still small in number and SAF supply methodologies are configured such that all SAF is blended to the bare minimum mandated. Furthermore, there is too little SBC available to achieve high blend percentages, which reinforces the argument that quantity should precede quality. In due time, however, when such constraints are alleviated and more SBC becomes available, an increase in blend ratios and the removal of the blend wall will be required to attain a higher sustainability impact of SAF in flight.

8.3. Validity and reliability

The validity and reliability of the research were strengthened throughout the research process through the sampling of relevant stakeholder groups, triangulation of interview findings with existing literature, and systematic refinement of the coding and analysis process.

First, construct validity was strengthened by ensuring that the sample covered a broad range of stakeholder perspectives relevant to the implementation of SAF and the uptake of blending. As described in chapter 4, a comprehensive stakeholder analysis of the SAF industry was performed to identify relevant actors along the participation continuum. Based on this analysis, seven stakeholder categories were identified as most relevant to the research. From these categories, a total of 14 specialists in the alternative aviation fuel industry were interviewed, with no more than three subjects selected from each category. This approach reduced the risk that the findings would be dominated by the perspective of a single stakeholder group and allowed barriers and measures to be analysed from different perspectives. Construct validity was further strengthened through triangulation between the interview findings and the existing literature. The literature review informed the formulation of the interview questions and the initial longlist of codes as specified in Appendix D, while findings from the interviews were subsequently compared with the literature. This iterative process provided a basis for assessing whether identified barriers and measures were consistent with existing knowledge, while also allowing findings that were not identified in the literature to emerge from the interviews. Through such triangulation, the analysis did not rely solely on the perceptions of individual interviewees.

Second, internal validity was strengthened by analysing not only the barriers, but also their underlying causes and potential measures within the TIS framework. This allowed relationships between barriers, their causes, and possible solutions to be considered rather than considering the identified barriers as isolated observations. The use of different stakeholder groups further supported this process, as differences and similarities between stakeholder perspectives could be considered during the interpretation of the findings. The use of semi-structured interviews also contributed to the validity of the findings. All participants were presented with the same set of questions, providing a consistent basis for comparison across interviews. Simultaneously, the semi-structured format of the interviews allowed for flexibility in the discussion based on the responses of individual participants to explore insights in greater detail. This allowed predefined topics to be addressed while limiting the risk that relevant insights would be excluded because they were not anticipated during the design of the interview protocol.

Finally, reliability was strengthened through the iterative coding approach applied to interview data. An initial longlist of codes was derived from the findings of the literature review, which was continuously refined as new insights emerged from the interviews. Codes were added, removed, merged, or rephrased where necessary to maintain a coding structure that reflected the interview data and remained focused on the central phenomenon under investigation. The iterative coding approach also supported the assessment of data saturation. As documented in Appendix D, subsequent interviews resulted increasingly in the refinement, merging, and removal of existing codes rather than the identification of new codes. This suggests that additional interviews were providing diminishing amounts of new information and that the central barriers and measures had been sufficiently captured within the scope of the study.

8.4. Limitations

Although the results of this research are extensive in their analysis, there are also certain limitations that must be considered. In no particular order, these are listed below:

1. **Limited ecosystem analysis**: although many of the stakeholders in the SAF ecosystem were incorporated into the research sample, a few groups were not sufficiently represented. For example, while passengers were excluded because of their limited expertise in SAF, their perspective as outsiders to the industry may hold insights that are unbeknownst to the industry. The same holds true for individuals from environmental NGOs and private investors, who may have less expertise in SAF but could respectively better represent a stakeholder from a pro-environmental or a financial point of view.
2. **Limited generalizability**: inherent to a qualitative research design is the low sample size. Although a total of 14 participants were interviewed, the sample was designed to incorporate a

wide range of different stakeholders. As a result, this yields no more than three experts per stakeholder group. The aviation industry in the European Union (EU) alone counts thousands of companies ranging from fuel suppliers to original equipment manufacturers (OEMs), which is why the results assumed from the sample size cannot be generalized for the entire SAF industry in the EU. In addition, while this sample is aimed to be representative of the SAF industry in the EU, a majority of participants were sampled from the Netherlands for the sake of convenience. This begs the question whether the perspectives shared by experts can be generalized for the EU.

3. **Geographic scoping**: as mentioned in chapter 4, this research limits itself to the SAF industry in the EU region, which thus assumes that interregional policy-making does not affect the development of a strategy. As has been showcased in the results, however, this does not hold true as aviation is an international market with many dependencies that need to be incorporated. Only by taking into account developments and events to some degree in e.g. the US and Asia, a fully exhaustive research design can be conceived.
4. **Exhaustive SBC analysis**: as explained in chapter 6, analysis of SBCs was limited to HEFA, power-to-liquids (PTL), ATJ, FT, and CHJ. Due to the low relevance of other SBCs and subtypes, namely synthesized iso-paraffins (SIP), co-processing, and hydrocarbon-HEFA (HC-HEFA), these were neglected in the analysis. However, especially with regards to co-processing, these pathways could hold significant value in future uptake of SAF, potentially being able to blend up to 100% and producing large SAF quantities that are cost-competitive with HEFA.
5. **Legitimacy and feasibility of measures**: measures were fully induced from interview responses, the legitimacy and feasibility of which have not been analysed due to the limited scope of the research. While none of the measures were found to be contradictory, it cannot be stated which measures are more easily attainable or efficacious. Consequently, no statement can be made about which barriers are easier to overcome than others.
6. **Reinforcement of existing concepts**: interviews were held across the span of two months, with gaps between interviews ranging anywhere from two weeks to two hours. Provided the sequential order of interviews, concepts that are discovered in early stages of the data collection process may be reinforced in later stages of the process due to the semi-structured format of the interview. While this should not heavily impact the data analysis because rates of occurrences are not used as a means to represent the significance of one code over another, it may cause an interview to be guided in a different direction than if the interview were held without any prior knowledge.
7. **Researcher bias**: despite the many measures used to ensure validity and reliability, the interpretation of the text remains subjective, which may introduce some bias provided the positionality of the author. Although this bias could be reduced through multiple, parallel analyses, this cannot be eliminated within the scope of this research.

9
Conclusion

To conclude, this chapter aims to answer all previously stated sub-research questions as well as the main research question in section 9.1 and section 9.2 respectively. Additionally, the chapter provides recommendations for future research in section 9.3.

9.1. Answering sub-research questions

This section aims to answer each of the three sub-questions previously stated. These are discussed in their respective sections below.

> **RQ1:** Which stakeholders are involved in the transition toward higher SAF blend ratios?

Although it can be argued that all stakeholders are involved in the transition toward higher sustainable aviation fuel (SAF) blend ratios, not all stakeholders share equal involvement. Depending on their level of participation and cooperation, stakeholders are placed in a participation continuum based on Carrera et al. (2021)'s involvement model and Bammer (2019)'s IAP2 spectrum, distinguishing between seven levels of participation ranging from "ignorance" to "empowerment". From this, it is found that stakeholders with limited participation ("ignorance" and "awareness") are least likely to be involved, because they perform their function independently from any other stakeholders with very limited influence on the SAF ecosystem. Stakeholders who are noted to be well-informed, alongside stakeholders who consult, discuss, collaborate, or are empowered with other stakeholders, are more impactful in the transition, often categorized as key stakeholders. With regard to the latter, *under a stakeholder's typical operational role*, this includes regulators and certification bodies, SAF suppliers, distributors, airlines and airports, equipment manufacturers, research institutions and external advisory consultants, private and public investors, and collaborative platforms. More crucially, however, the involvement model is not meant to assign fixed positions to stakeholders. Depending on the context, different levels of participation among certain stakeholders may be assumed. Therefore, stakeholders can occupy different positions in the participation continuum, which results in a dynamic level of involvement during the transition toward higher SAF blend ratios.

> **RQ2:** What types of barriers currently prevent SAF blending beyond 50%, and do these barriers differ across synthetic blending components?

First and foremost, it was found that SAF blending beyond 50% holds little to no priority among the SAF industry. This is because there is currently too little synthetic blend component (SBC) available to achieve high blend percentages. Furthermore, regulatory limits do not instil an urgency to increase blends. With a current mandated share of 2%, higher SAF shares and higher SAF blends would only be warranted by an increase in the mandated blend share, which would only pose a problem in the long term. In a similar vein, because of fuel supply methodologies, high-blend SAF batches are diluted to the bare minimum mandated by ReFuelEU aviation along the supply chain, which means breaking the blend wall holds limited impact until the mandate increases. Therefore, the industry currently prioritizes quantity over quality, with efforts aimed at upscaling future uptake of SAF. However, when such barriers are removed, and more SBC becomes available in the future, an increase in blend ratios and removal of the blend wall will be necessitated to achieve a higher sustainability impact of SAF in flight.

Secondly, to then dissect the barriers which prevent further uptake of SAF, it is found that most Technological Innovation System (TIS) building blocks are still only partly compatible or incompatible. The exception to this is complementary infrastructure and services (F4), because SAF is allowed to use the same means of transport as Jet A-1 when certified. Meanwhile, product performance and quality (F1), innovation-specific institutions and industry-wide regulations (F5), network formation and coordination (A1), and customers (A2) are partly compatible. With regard to F1, SAF can already be used in the current aircraft fleet, but this is constrained to blends of 50% due to the constraint of aromatic content in fuels. Further development of drop-in SAF with aromatics, however, is well underway. As for F5, institutions and regulations are also widely in place, although scattered and unclear. Without a clear governance structure, regulatory burdens derived from compliance, and regulatory fragmentation on the national, intra-regional and inter-regional level, there are significant structural inefficiencies in the SAF industry. When it comes to A1, there are many collaboration and coordination processes in place. However, limited participation and coordination between certain actors can be perceived as stakeholders continue to prioritise individual competitive position over shared, collective benefit. Although voluntary uptake among customers (A2) is growing, knowledge and awareness are still limited. Passengers may be willing to pay the costs incurred by uptake of SAF, but this requires trust and knowledge to be built - not just among customers, but among the entire industry. Finally, the product price (F2) and production system (F3) are entirely incompatible to compete with competitive products. With regards to the former, the most cost-efficient SAF with incentives in place is still at least twice as expensive as conventional Jet A-1. With regards to the latter, although the European Union (EU) is currently in an oversupply market, production systems in place will not be able to keep up with the ramp-up speed of the mandate because of long construction times and high investment costs, but also due to unforeseen technological challenges. E-SAF technology has such a low technological maturity that it is deemed likely that required e-SAF sub-mandates will not be met in 2030.

Finally, to understand whether these barriers differ across SBCs, a comparative SBC analysis was performed. The results indicate that SBCs can be distinguished on the basis of three main barriers: product performance and quality (F1), product price (F2), and production system (F3). With regard to F1, all paraffinic SBCs face challenges with regard to the 50% blend wall due to their lack of aromatic content. Therefore, drop-in options such as Fischer-Tropsch synthetic aromatic kerosene (FT-SKA), catalytic hydrothermolysis jet (CHJ), and alcohol-to-jet synthetic aromatic kerosene (ATJ-SKA) are more likely to develop on this front as they are not constrained by this limitation. Synthetic aromatic kerosene (SAK) could also be blended with synthetic paraffinic kerosene (SPK)-type fuels, but this remains in development and is projected as a solution for the long term. In the context of F2 and F3, hydro-processed esters and fatty acids synthetic paraffinic kerosene (HEFA-SPK) holds the highest maturity and lowest cost on the SBC market. Meanwhile, FT and ATJ technologies are still underdeveloped with respect to HEFA-SPK, but fall under the same mandated share of bio-SAF. Thus, they are minimally stimulated because they are underdeveloped and more expensive. Thus, their contribution to the fuel pool remains minimal, at least until HEFA-SPK production runs dry. Although power-to-liquids (PTL) production pertains to a distinct sub-obligation, it faces even more difficulty to overcome such challenges because its maturity and cost are respectively lower and higher than other SBCs, partially also due to its energy-intensive processes. Promising developments in this forefront concern methanol-to-jet (MTJ), which allows production of e-SAF through a larger pool of available feedstocks.

> **RQ3:** Which technical, regulatory, and market-related measures could enable SAF blending beyond the current limit?

Paired with each identified key challenge comes an array of measures that enable the industry to overcome these challenges. Mandates and regulations alongside incentives and subsidies are the two most frequently named types of measures, noting their significance in bridging challenges specifically with regards to price (F2), quantities (F3), and regulations (F5). In actor-specific challenges - concerning A1 and A2 - emphasis is instead placed on knowledge building and sharing, networking, and raising public awareness. The same holds true for quality and performance (F1) and infrastructure (F4), respectively requiring further developments in technology and designated infrastructure to alleviate bottlenecks. Altogether, it can be concluded that different TIS building blocks require different levels of participation among stakeholders dependent on the context of the challenges and coupled measures. Not every stakeholder may be equally suitable for overcoming all challenges, but every key stakeholder plays some essential role in helping overcome one or more barriers to the introduction of SAF to the aviation industry. Through the mapping of stakeholders for (f)actor-specific challenges, collaboration and coordination processes among stakeholders are further enhanced.

9.2. Answering main research question

This section aims to answer the main research question stated below, formulating a strategy for the SAF ecosystem to unlock future uptake of SAF.

> **MRQ:** What roles can individual stakeholders fulfil to facilitate the transition toward higher SAF blend ratios?

The answer to this main research question synthesizes the answers to the previous sub-questions, i.e., the stakeholder analysis in chapter 4, barrier analysis in chapter 5, and coupled measures in chapter 7. Because not all building blocks are compatible, large-scale diffusion is not yet possible. As opposed to formulating a niche introduction strategy from a company perspective as proposed by Ortt and Kamp (2022), the conclusion below formulates a strategy from a multi-actor perspective to be used as an industry-wide solution. Provided the mapping of stakeholders along the participation continuum, different levels of involvement are distinguished among stakeholders to undertake the measures coupled to challenges presented in a TIS building block. Through use of this model, roles are directly appointed which individual stakeholders can fulfil to facilitate the SAF transition, not just toward higher SAF blend ratios, but an increased uptake of SAF altogether.

First, aviation regulators, regional governments, certification bodies, national governments, and public investors can often be found working closely together, but sometimes only specific stakeholders are relevant to resolving the challenges at large. For regulatory challenges, aviation regulators and regional governments take the lead, with certification bodies and national governments as collaborators to remove structural inefficiencies in the SAF industry due to regulatory fragmentation. By effectively using regulatory and monetary instruments such as increased flexibility in the list of available feedstocks, the introduction of a book-and-claim system for the SAF supply chain, the implementation of Contracts for Difference (CfDs), or the harmonization of EU mandates with other international mandates, this creates a more favourable investor climate in the EU. Meanwhile, price-related challenges solely place national and regional governments in a role of empowerment with collaboration from public investors while sidelining aviation regulators and certification bodies. Governmental bodies should invest in grid expansion, automation, and digitalization to respectively reduce electricity cost, increase potential refinery output, and reduce administrative burdens for airlines to make Emission Trading System (ETS) claims. Despite this extensive list of possible measures, it should also be noted that these authoritative stakeholders are not always crucial to overcoming certain barriers: performance- and quality-related challenges do not require regulators and governmental bodies, who rather assume an informed or consultative role.

Second, SAF suppliers, airlines, distributors, and private investors can take up a wide range of roles, of which SAF suppliers and airlines often find themselves in the higher rungs of the participation continuum. Performance- and quality-related challenges, which do not require as much participation from authoritative figures due to their technical nature, rather places SAF suppliers in a role of empowerment. In collaboration with original equipment manufacturers (OEMs), research institutions, and external advisory consultants, they should further investigate future technology developments concerning production uncertainties, the 50% blend limit, and low technology readiness level (TRL)-type SBCs such as ATJ, FT, and e-SAF. Future solutions such as SAK and MTJ should be co-developed and qualified using funding made available by investors. As for customer-related challenges, all stakeholders along the supply chain assume a collaborative role. Airlines can stimulate the uptake of the general public by increasing public awareness and trust in SAF technology through accessible mediums of communication, while SAF suppliers and distributors should further stimulate uptake of SAF through CO_2-reduction certificates among private firms. Finally, distributors are placed in a role of empowerment when it comes to infrastructure-related challenges, provided their role is to operate, maintain, and improve the current infrastructure.

Third, airports, OEMs, research institutions, and external advisory consultants often take up a position in the lower half of the participation continuum, often remaining informed, being consulted, or joining discussions. These stakeholders are not primarily responsible for resolving many of the challenges that the SAF industry faces, but support those that are. The sole exception to this lies with performance- and quality-related challenges where OEMs, research institutions, and consultants assume a collaborative role due to the technical nature of the challenges.

Fourth, collaborative platforms are among the most versatile types of stakeholders. In actor-specific challenges, collaborative platforms should take the lead in establishing industry-wide communication platforms for increased knowledge sharing and transparency between stakeholders. This dissolves imbalances in power and influence, increases industry transparency and trust, and enables equitable knowledge co-production. Meanwhile, in performance-, quality-, and price-related challenges, collaborative platforms should ensure they join discussions. They may not hold many valuable resources outside their ability to network and gather knowledge, but their role as moderator in discussions can help enrich the problem-solving process and ensure a coordinated strategy among the industry.

To conclude, different TIS building blocks require different levels of participation among stakeholders dependent on the context of the challenges and coupled measures. Not every stakeholder may be equally suitable for overcoming all challenges, but every key stakeholder plays some essential role in helping overcome one or more barriers to the introduction of SAF to the aviation industry.

9.3. Future research

Although many avenues are explored in this research, there are numerous more that could be explored in further depth to better understand the complexities of the SAF industry and how literature regarding technology transitions could help inform policymakers about which future actions to take. These are summarized in the list in no particular order below.

1. **Comparative analysis between challenges**: although a comparison was drawn between multiple prominent SBCs, there are more comparisons which can be drawn between different elements of the analysis. One of these would pertain to the different challenges observed in each TIS building block. Rather than categorizing barriers in one of three classes - ”incompatible”, ”partly compatible”, and ”compatible - the results become more actionable by assigning a degree of priority and difficulty. These measures could be extracted by sending an overview of all identified challenges to all participants in the sample and asking them to rate each item on a Likert scale from 1 to 10 based on their priority and difficulty to overcome. By using descriptive statistics, this could then further visualise where the priorities in the SAF industry lie and how difficult the industry perceives each challenge to be. These results, in turn, can also be compared across stakeholder groups to investigate whether opinions in the industry align or diverge from each other.
2. **Technology dynamics of SBCs**: fit-for-purpose properties, feedstock availability, and TRL are attributed as the three primary measures to understand future developments of different SBCs. Notably, many participants envision HEFA transitioning into ATJ and FT, which could subsequently transition into e-SAF. This dynamic within the SBC market bears resemblance to the dynamics between radical and incremental innovation and could be a future avenue to explore to understand the development of future SBCs. CHJ, although also showing signs of potential, is currently insufficiently included in discussions and would benefit from being further investigated for overcoming identified challenges in the SAF industry.
3. **TIS from a multi-actor perspective**: this research approached the TIS framework from a multi-actor perspective rather than from a company perspective, which produced new insights with regard to the analysis of customers (A2) and the formulation of a strategy. However, because this was not the focal point of the research, the TIS framework could be further investigated from the multi-actor perspective with potential applications for industry-wide solutions. It would

be recommended to then expand on the formulation of strategies by incorporating stakeholder participation or collaboration models into the TIS framework as a means of formulating strategies for multiple actors based on their available collective resources and knowledge, similar to what has been proposed in this research.

4. **Verification of strategic measures**: although strategic measures were formulated, these could not be verified for their viability. By further verifying a measure's legitimacy and feasibility, results could become more applicable to a real-life scenario. Although this requires a better understanding of the inner workings of the SAF industry, such tools would provide an alternative means to compare the difficulty of one challenge over another.

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A

Reflection on usage of AI tools

In the process of completing this research, limited use was made of generative AI tools. During the literature study, I felt that it was appropriate to gather information independently of generative AI tools in order to get sufficient personal understanding of the literature. When this option was exhausted, however, ChatGPT was used as an additional source of generating information, simultaneously used as a means of cross-checking and validating the already existing database of information. If ChatGPT listed missing information, the data was retraced to its source to ensure that factual information was listed. Aside from gathering new sources, ChatGPT was also used to help restructure the research. Similarly to above, I felt it was appropriate to write out the content and lay-out myself to shape the research that I envision. Once this was completed, some parts were revised following small spelling and grammar corrections suggested by ChatGPT. However, I made sure to analyse the suggestions and implement those which I agreed with. In sum, generative AI may not always be factual, and it is important to keep a human factor in the loop to assess its outputs. While generative AI may be stronger in some fields than others, I believe it should rarely be trusted blindly.

B

Stakeholder analysis of the SAF industry

Below, stakeholders are listed in accordance with the number they represent in the stakeholder ecosystem alongside a short description. Stakeholders 25 to 27 are excluded from the ecosystem because they are not involved with SAF, however, they are direct competitors to SAF suppliers and therefore relevant to include in the list below.

1. **Aviation regulators** (e.g. FAA, EASA): Enforce aviation regulations concerning production and use of SAF
2. **Regional governments** (e.g. European Commission): Develop region-wide policies, mandates and incentives to define and stimulate the SAF industry
3. **Certification bodies** (e.g. ASTM, ICAO): Define technical standards and certification criteria that SAF pathways must adhere to enter the market
4. **National governing bodies** (e.g. I&W, ILT, NEa): Translate international policies into national laws, standards, and procedures to put into effect
5. **Clearing houses** (e.g. EU SAF Clearing House): Facilitate SAF testing and qualification procedures to accelerate commercialization
6. **SAF suppliers** (e.g. Neste, SkyNRG, World Energy): Produce synthetic blend components (SBCs) from approved feedstocks and pathways, which are (optionally) blended and sold
7. **Feedstock suppliers** (e.g. agricultural sector, waste sector, renewable energy sector): Provide feedstock required for SAF production, such as sugars, crops, oils, fats, municipal solid waste (MSW), biomass, renewable energy, or carbon
8. **Technology providers**: Develop technology and equipment used to produce SAF
9. **Distributors** (e.g. DPO, CEPS, Port of Rotterdam): Manage storage, logistics, and transport of SAF
10. **Airlines** (e.g. KLM, Lufthansa): Purchase SAF to reduce emissions and meet mandates or sustainability targets
11. **Airports** (e.g. RTHA, Schiphol): Provide infrastructure for handling of SAF
12. **Fuelling personnel**: Conduct handling of SAF along the supply chain, from production to use
13. **Passengers**: Fly with commercial airlines, can contribute to voluntary SAF uptake through opt-in programmes
14. **Corporate customers** (e.g. cargo transport, business travel): Can purchase SAF or SAF certificates to reduce emissions under the Business Aviation sector
15. **Equipment manufacturers** (e.g. Airbus, Boeing, Rolls-Royce, GE Aerospace): Design, test, and certify airframes and engines for compatibility with SAF blends, working towards drop-in-compatible aircraft

16. **Research institutions** (e.g. TU Delft, NLR, DLR, TNO): Conduct research on SAF concerning feedstocks, pathways, fuel properties, and climate effects to support the qualification of new pathways and higher blends
17. **External advisory consultants** (e.g. To70, ICF): Advise stakeholders on strategy, regulatory compliance, and SAF market developments
18. **Private investors** (e.g. Qantas, Airbus, Total Energies, Neste, Verve Ventures, Contrarian Ventures): Provide equity and venture capital to develop and scale SAF production technologies and capacity
19. **Public investors** (e.g. national governments, multilateral development banks (MDBs), development finance institutions (DFIs) such as the EBRD, FMO or IFC): Provide grants, loans, and de-risking instruments to narrow the price gap for SAF projects
20. **IT partners** (e.g. CHOOOSE): Offer digital platforms to assist in SAF procurement, distribution, and MRV (monitoring, reporting, and verification) compliance
21. **Collaborative platforms** (e.g. RSB, CAAFI, SABA, NAG): Offer platforms for stakeholders across the value chain to collaborate and coordinate efforts, sharing knowledge and aligning values
22. **Contractors** (e.g. Fluor Corporation, Technip Energies, Bechtel): Provide engineering, procurement, and construction (EPC) services for SAF refineries
23. **Test partners** (e.g. Intertek, Bureau Veritas, Airbus, Rolls-Royce): Perform fuel tests and lab analysis required for the qualification of SAF
24. **Environmental NGOs** (e.g. ICSA, Stay Grounded, ClimateWorks Foundation, AEF, T&E): Advocate for environmental considerations, scrutinizing SAF market developments and influencing public opinion and policy-making
25. **Feedstock competitors** (e.g. renewable diesel producers, food industry): Compete with SAF producers for the same pool of materials and feedstocks such as used cooking oil (UCO) or energy crops
26. **CAF suppliers** (e.g. Shell, ExxonMobil, BP, TotalEnergies): Produce and sell conventional aviation fuel (CAF), directly competing with SAF
27. **Energy companies** (e.g. Vattenfall, Statkraft, Fortum): Generate and sell renewable electricity and hydrogen, competing with e-SAF production for limited renewable energy capacity

C Interview protocol

Attached below is the printed version of the interview protocol used as guideline for conducting the semi-structured interviews. To summarise, the interview starts with an introduction in question 1 and 2, after which the SAF blend limit and barriers that hamper an increase in SAF blend ratios is discussed in questions 3 to 6. Question 7 helps better understand these barriers, whereas questions 8, 9, and 10 explore possible solutions. Finally, question 11 closes off the interview.

Interview Protocol

Title: Breaking the Blend Wall
Date: DD/MM/YYYY
Interviewee: FirstName LastName (Position, Company)
Actor Group: GroupName
Interview Code: XX-Y (XX = Group Identifier, Y = Number)
Interviewer: Luke Willigenburg

[Opening + Consent Statement - Signed]

[Start of Recording]

Introduction

a. **Q1**: Can you briefly explain how you / your organisation currently engages with SAF and what role you play in this?

Context

a. **Q2:** How is the current 50% blending limit reflected in practice? Is it something that actively constrains the SAF industry *(alternative: your operations)*, or more of a formal boundary?

Barriers

a. **Q3:** From your perspective on the SAF industry, to what extent do you think SAF blend ratios can be increased beyond the blend limit in the next 5 years?
    i. If the interviewee does not explain the reason behind a change in blend ratios and SAF shares, ask why.
    ii. Note down any mentioned status of building blocks. Emphasize barriers (causes).
    iii. If the interviewee cannot name anything, give them an example.
b. **Q4:** Do you think that certain SAF pathways are more likely to achieve higher blend ratios than others in the aviation industry? Or can this be generalised across all pathways?
    i. Regardless of whether the interviewee agrees or disagrees, ask why.
c. **Q5:** Based on your assessment of the SAF industry, which barrier(s) do you believe is/are the most difficult to overcome?
    i. Note down the most critical barriers.
    ii. Ask why the interviewee thinks these barriers are difficult to overcome.
d. **Q6:** Inversely, which barrier(s) do you think is/are easiest to overcome?
    i. Note down less critical barriers.
    ii. Ask why the interviewee thinks these barriers are easy to overcome, and why they have not yet been overcome.

Influencing Conditions

a. **Q7:** You mentioned [barrier], but can you explain to me why [barrier] exists in the first place? (*Alternatively: What is/are the underlying reason(s) for these barriers to exist in the first place?)*
    i. Note down the mentioned underlying cause. Repeat for any other mentioned barriers.
    i. If the interviewee cannot name anything, give them a possible example.

Strategies

a. **Q8:** What measures could be undertaken to facilitate higher blend ratios?
    i. Note down any measures.
b. **Q9:** Who are the relevant actors to undertake these measures?
    i. Note down any relevant actors.
    ii. If more than one actor is mentioned, ask whether they should work independently or collaborate.
c. **Q10:** In such a collaboration, are there certain stakeholders who would need to take the lead and are more responsible for achieving this change than others?

Closing

a. **Q11:** If you could change one thing about the SAF industry to facilitate the transition to higher SAF blend ratios, what would it be?

[End of Recording]

D

Longlist of codes

In Table D.1 and Table D.2 below, the evolution of the longlist is recorded over time.

In Table D.1, the left and right columns respectively display the list of codes induced by literature and after 3 interviews. Between the first and the second column, a lot of codes are altered: ”airline competitiveness” is extended to ”international market competition”, ”conflict” is adjusted to ”conflict of interest”, and so on. In addition, irrelevant codes were removed, such as ”lack of central authority”, ”life cycle assessment”, or ”undefined problem formulation”. Meanwhile, new codes were also added to the new list of codes, such as ”market accessibility”, ”power and influence”, or ”system compatibility”.

The same process holds true for Table D.2, although this table rather displays the process of refining and removing codes to eliminate excessive information to focus on the central phenomenon, such as ”limited lifetime”, ”limited funding”, or ”transfer of ownership”. Again, some codes received slight rephrasing, such as ”trade-off” to ”sustainability trade-offs” or ”priority paralysis” to ”priorities”. In the final column, additional codes were merged with existing ones, which ultimately yields a longlist of 74 codes in total, of which 10 are attributed to types of actor roles, 13 to types of measures, and the other 49 to TIS building blocks and influencing conditions.

Table D.1: Longlist of codes based on literature and after 3 interviews

Code (literature)	**Code (3 interviews)**
airline competitiveness	actor
ambiguous requirements	actor: administration
conflict	actor: collaboration and coordination
different certification bodies	actor: demand
divergent international playing field	actor: financing
feedstock impurity	actor: operation
feedstock variability	actor: regulation
fragmented regulations, standards, and policies	actor: research
greenwashing	actor: supply
high certification costs	collaboration and coordination

Code (literature)	Code (3 interviews)
high operational costs	commingled logistics
high production costs	conflicting interests
high transport costs	conservatism
inefficacious incentives and subsidies	construction time
inefficient feedstock transformation	cross-sector competition
investment risk	economies of scale
knowledge creation	energy cost
lack of capital supply	environmental impact
lack of central authority	european autonomy
lack of communication	expensive
lack of consensus	extensive approval processes
lack of cooperation	feedstock availability
lack of demand-driven policies	feedstock variability
life cycle assessment	fragmented regulatory landscape
limited energy efficiency	geographical advantages
limited feedstock availability	high investment costs
limited regulatory mechanisms	high legal consequences
logistical constraints	insufficient quantities
long certification cycles	international dependency
low quality	international market competition
low SAF yield	lack of infrastructure
low technological maturity	lack of participation
low willingness to pay	limited demand
public skepticism	limited funding
safety	limited knowledge
small-scale production	limited lifetime
stakeholder negotiation	limited technological maturity
stakeholder participation	limited voluntary uptake
uncertainty	lobbying
undefined problem formulation	low willingness to pay
unsustainable feedstock sourcing	market accessibility
	market uncertainty
	measure
	measure: changes to regulation
	measure: changes to regulation
	measure: clear governance structure

Code (literature)	Code (3 interviews)
	measure: dedicated SAF allocation
	measure: designated infrastructure
	measure: incentives and subsidies
	measure: increased regulatory pressure
	measure: investments
	measure: knowledge sharing
	measure: networking
	measure: raising public awareness
	measure: risk coverage
	measure: simplify integration
	measure: stakeholder mapping
	measure: stimulate voluntary uptake
	measure: technology development
	noise
	power and influence
	price volatility
	priority paralysis
	production cost
	production uncertainty
	public perception
	public trust
	regulatory burdens
	regulatory constraints
	regulatory firmness
	regulatory gap
	safety concerns
	small operating margins
	supply chain optimization
	sustainable feedstock sourcing
	system compatibility
	technological hybridization
	testing and maintenance
	traceability
	trade-off
	transfer of ownership

Code (literature)	Code (3 interviews)
	unclear governance structure

Table D.2: Longlist of codes based on 3 interviews, 14 interviews, and finalised version

Code (3 interviews)	Code (14 interviews)	Code (finalised)
actor	actor	actor
actor: administration	actor: administration	actor: administration
actor: collaboration and coordination	actor: certification	actor: certification
actor: demand	actor: collaboration and coordination	actor: collaboration and coordination
actor: financing	actor: demand	actor: demand
actor: operation	actor: financing	actor: financing
actor: regulation	actor: operation	actor: operation
actor: research	actor: regulation	actor: regulation
actor: supply	actor: research	actor: research
collaboration and coordination	actor: supply	actor: supply
commingled logistics	collaboration and coordination	blending uncertainty
conflicting interests	commingled logistics	collaboration and coordination
conservatism	conflict of interest	commingled logistics
construction time	conservatism	conflict of interest
cross-sector competition	construction time	conservatism
economies of scale	cross-sector competition	construction time
energy cost	economies of scale	cross-sector competition
environmental impact	energy cost	economies of scale
european autonomy	environmental impact	energy cost
expensive	european autonomy	environmental impact
extensive approval processes	expensive	european autonomy
feedstock availability	extensive approval processes	extensive approval processes
feedstock variability	feedstock availability	faulty industry norm
fragmented regulatory landscape	feedstock variability	feedstock availability
geographical advantages	fragmented regulatory landscape	feedstock variability
high investment costs	geographical advantages	geographical advantages
high legal consequences	high investment costs	high investment costs
insufficient quantities	high legal consequences	high price levels
international dependency	insufficient quantities	insufficient quantities
international market competition	international dependency	inter-regional regulatory fragmentation

Code (3 interviews)	Code (14 interviews)	Code (finalised)
lack of infrastructure	international market competition	international dependency
lack of participation	lack of infrastructure	international market competition
limited demand	lack of participation	intra-regional regulatory fragmentation
limited funding	limited demand	lack of infrastructure
limited knowledge	limited knowledge	lack of participation
limited lifetime	limited technological maturity	limited demand
limited technological maturity	limited voluntary uptake	limited knowledge
limited voluntary uptake	lobbying	limited technological maturity
lobbying	local supply chain differences	limited voluntary uptake
low willingness to pay	low willingness to pay	lobbying
market accessibility	market accessibility	low willingness to pay
market uncertainty	market uncertainty	market accessibility
measure	measure	market uncertainty
measure: changes to regulation	measure: book-and-claim	measure
measure: changes to regulation	measure: clear governance structure	measure: book-and-claim
measure: clear governance structure	measure: dedicated SAF allocation	measure: capital investments
measure: dedicated SAF allocation	measure: designated infrastructure	measure: clear governance structure
measure: designated infrastructure	measure: incentives and subsidies	measure: dedicated SAF allocation
measure: incentives and subsidies	measure: integration efforts	measure: designated infrastructure
measure: increased regulatory pressure	measure: investments	measure: incentives and subsidies
measure: investments	measure: knowledge building and sharing	measure: knowledge building and sharing
measure: knowledge sharing	measure: mandates and regulations	measure: mandates and regulations
measure: networking	measure: networking	measure: networking
measure: raising public awareness	measure: raising public awareness	measure: raising public awareness
measure: risk coverage	measure: risk coverage	measure: risk coverage
measure: simplify integration	measure: technology development	measure: technology development

Code (3 interviews)	Code (14 interviews)	Code (finalised)
measure: stakeholder mapping	noise	national-regional regulatory fragmentation
measure: stimulate voluntary uptake	power and influence	noise
measure: technology development	price volatility	power and influence
noise	priorities	price volatility
power and influence	production cost	priorities
price volatility	production uncertainty	public perception and trust
priority paralysis	public perception	regulatory burdens
production cost	public trust	regulatory gap
production uncertainty	regulatory burdens	safety concerns
public perception	regulatory constraints	small operating margins
public trust	regulatory firmness	supply chain optimization
regulatory burdens	regulatory gap	sustainability trade-offs
regulatory constraints	safety concerns	sustainable feedstock sourcing
regulatory firmness	small operating margins	system compatibility
regulatory gap	supply chain optimization	technological hybridization
safety concerns	sustainability trade-offs	testing and maintenance
small operating margins	sustainable feedstock sourcing	training
supply chain optimization	system compatibility	unclear governance
sustainable feedstock sourcing	technological hybridization	
system compatibility	testing and maintenance	
technological hybridization	traceability	
testing and maintenance	training	
traceability	unclear governance	
trade-off		
transfer of ownership		
unclear governance structure		