Master's Thesis – Master Innovation Sciences

Technological Niches of Sustainable Aviation Fuel

Socio-Technical Configuration Analysis of the Dutch Socio-Technical System of Aviation Fuel

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Submission Date	26-05-2024
Words	20312

Abstract

The continuously growing aviation sector is responsible for 7% of Dutch CO2 emissions and is one of the most difficult sectors to abate emissions. Sustainable Aviation Fuel (SAF) is considered as a promising pathway to reduce these CO2 emissions. SAF can be classified into synthetic kerosene and three distinct generations of biokerosene. First-, second- and third-generation biokerosene as well as the later emerging synthetic kerosene were initially developed within a technological niche, having been supported by a small network of actors and institutions in a protected space apart from the established regime.

This thesis seeks to understand how and under what circumstances technological niches of SAF can reconfigure the regime of the Dutch socio-technical system of aviation fuel. It thereby questions whether the breakthrough of a technological niche is, apart from the internal niche processes and necessary 'windows of opportunity' suggested by SNM scholars within existing literature, moreover depends on additional conditions.

Socio-Technical Configuration Analysis (STCA) was employed in this study. This method was utilized to study prevalent 'storylines' and 'advocacy coalitions' in three distinct phases of the public discourse of this sector. Connections between actors and concepts were discerned from actor statements recorded in Dutch public newspapers and coded in an iteratively developed coding scheme in NVivo. Co-occurrences between actor and concept codes were exported as matrices, processed through an R script and ultimately visualized as 'concept congruence networks' and 'actor congruence networks' in Visone. Both the networks and the qualitative nature of the data allowed for analysing the emerging socio-technical configurations and the established configuration, as well as the impact of institutionalized actors and shifts in field logics on the Dutch socio-technical system of aviation fuel in Phase I, Phase II and Phase III.

The analysis revealed that the successful breakthrough of the niches of second-generation biokerosene and synthetic kerosene depended on internal niche development processes and a de-stabilized regime through the occurrence of critical moments. Moreover, relational power structures of actors within the dominant field logic exerting influence on these niches through their institutional support was identified as a condition for success. Also, the alignment of these technological niche with the dynamics of the existing regime, through hybridization of old and new technology, was found to be a necessary circumstance. Furthermore, learning processes accumulated within stabilized niches could be leveraged to the newly emerging niche of synthetic kerosene, serving as a 'springboard' for its development.

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1. Introduction

Every year, billions of tons of CO_2 are released into the atmosphere due to coal, oil and gas production and consumption (UN, 2019). Human activity is emitting greenhouse gas emissions at an unprecedented rate, with little signs of slowing down (UN, 2019). Consequently, climate change is a reality we must contend with: “temperatures are rising, drought and wildfires are starting to occur more frequently, rainfall patterns are shifting, glaciers and snow are melting and the global mean sea level is rising”, the European Environment Agency cautions (EEA, n.d.). The climate crisis is modern time´s biggest challenge and it requires urgent actions (EEA, n.d.). Therefore, in 2015, 195 countries laid the foundation for the most significant global climate agreement to date: the Paris Agreement (IPCC, 2022; Pérez et al., 2021). They agreed to limit the average global temperature increase by 2100 to “well below” 2 degrees Celsius above pre-industrial levels. Additionally, in their commitment to pursue greater efforts, they pledged to develop technologies aimed at limiting the temperature increase even further, to 1.5 degrees Celsius (IPCC, 2022; Pérez et al., 2021). The Netherlands ratified this agreement and, in conjunction with the EU, committed to reducing its emissions by at least 55% by 2030 compared to 1990 levels (Rijksoverheid, 2023a). Moreover, the Dutch government has established the ambitious goal of becoming a net-zero society by 2050. To attain these objectives, the Netherlands must direct its efforts towards its most polluting sectors.

One of the most difficult sectors to abate emissions, due to is high reliance on fossil fuels, long lifespan of the aircrafts and cost of alternative solutions, is the aviation sector (Shell, 2022). This continuously growing industry is responsible for 7% of Dutch CO_2 emissions and additionally has significant non-CO_2 climate effects, mainly due to water vapor, NO_x and SO_2 emissions (e.g., CBS, 2023; CE Delft, 2019; IenW, 2023a; Milieu Centraal, 2022). If these greenhouse gases were also to be taken into account, and expressed in CO_2-equivalents, as is done in other sectors, then the aviation sector could even be responsible for 15% of Dutch CO_2-equivalent emissions (IenW, 2023a; Schellekens, 2023). Hence, the Dutch government entered into agreements with the aviation sector regarding climate objectives, leading to the Sustainable Aviation Agreement in 2019 (IenW, 2023b). A cap will be imposed on the amount of CO_2 emissions stemming from flights departing from the Netherlands. The goal is to reach a 50% reduction in emissions by 2050 compared to the levels in 2005, with the ultimate aim of becoming completely carbon neutral by 2070 (IenW, 2020a).

To achieve these ambitious objectives, airlines, fuel producers, knowledge institutions and policy makers consider Sustainable Aviation Fuel (SAF) as a promising pathway to reduce CO_2 emissions (Duurzame Luchtvaarttafel, 2019). In 2021, conventional kerosine was blended with less than 1% sustainable fuels. By 2030, 6% of all aviation fuel used in the Netherlands should be sustainable and by 2050 a remarkable 100% (ILT, 2021; Nandram, 2023). SAF can be classified into two primary categories (CE Delft, 2017). The first one being synthetic kerosene, which is created with hydrogen and carbon dioxide captured from the atmosphere (CE Delft, 2017). Synthetic kerosene truly becomes sustainable only when the required electricity for hydrogen production is sourced from wind turbines or solar panels, green power that is often not yet readily available (Backers, 2023). Moreover, knowledge institutions such as NLR and Breda University of Applied Sciences often frame its production as excessively energy-intensive and costly (Backers, 2023; Canrinus-Moezelaar, 2020; Schuttenhelm, 2021). An advantage of synthetic kerosene is that it is relatively energy-dense, facilitating the convenient storage of significant quantities in tanks (Eshuis, 2023). Furthermore, it emits minimal harmful substances into the atmosphere upon combustion (Van de Weijer, 2021). The prevailing perspective within media discourse is that synthetic kerosene can play a significant role in the transition towards a more sustainable aviation sector, especially in the medium term (ILT, 2021).

Biomass-based kerosene, known as biokerosene, is the second primary category, with three distinct generations having evolved over time (Nanda et al., 2018). [1] First-generation biokerosene consists of ethanol derived from food crops, such as corn, soybeans, palm oil and rapeseed (Stimular, n.d.). Although it is occasionally referred to as renewable, this form of biokerosene can still lead to substantial greenhouse gas emissions due to deforestation, land use practices, agricultural methods and transportation (Stimular, n.d.). Environmental organisations also warn that it requires significant water consumption and extensive land usage, making it hardly more sustainable than conventional kerosene (Milieu Centraal, n.d.). Therefore, the aviation industry is striving to shift away from this first-generation biokerosene and focus more on other SAFs, that are indeed sustainable (NLR, 2021). KLM, for example, centres on second-generation biokerosene (KLM, n.d.). This type involves agricultural residues, such as straw, wheat bran or animal manure, as well as waste streams from the (food) industry, such as used cooking fat and residual vegetable oil (Stimular, n.d.). A third-generation biokerosene utilizes (micro)algae as a raw material to produce kerosene (Stimular, n.d.) Despite not being as commercially scaled, microalgae offer distinct advantages over the first two generations of biokerosene (Deltares, 2011; Doliente et al., 2020)). Due to their high photosynthetic efficiency, microalgae can absorb significant amounts of CO2 from the atmosphere and accumulate very high amounts of triglycerides, which is the major feedstock for biokerosene production (Deltares, 2011; Doliente et al., 2020). Additionally, algal biomass production is substantially higher than first- and second-generation biokerosene, thanks to algae's fast growth and rapid reproduction. Microalgae are also land-efficient because its cultivation does not require high quality agricultural land (Deltares, 2011). They can for instance be grown in salt water or organic wastewater, meaning it does not put extra pressure on fresh water supply (Deltares, 2011). However, this type of biokerosene is often framed in reports as having limited potential for scalability, alongside its technological challenges and concerns regarding its price-performance ratio (Koot, 2015).

Most of the technologies behind these aviation fuels have yet to mature and the technological and economic viability of SAFs remains under investigation in various academic fields (Kim et al., 2019). Numerous studies have examined the potential commercialization of SAFs within the aviation sector using methods such as lifecycle assessment or general equilibrium analysis (Kim et al., 2019). Apart from first-generation biofuels, SAFs have proven to achieve a substantial 80-90% reduction in emissions over the lifecycle of the fuel compared to traditional jet fuel (e.g., Air bp, 2022; Colelli et al., 2023; Desai, 2022; KLM, n.d.; Neste, n.d.). Although these studies offer valuable insights, the socio-technical challenges that dictate the commercialization of SAF remain largely unaddressed. A successful integration of SAF calls for an effective synergy between feedstock producers, SAF suppliers, airlines and the government (Kim et al., 2019). The interactions between these actors are accompanied by a wide array of interrelated social, economic and environmental issues. An analysis that focuses solely on one of these issues therefore provides limited understanding into the adoption of SAF. Following Kim et al. (2019), "there is a need for a comprehensive analysis of systemic transition that captures the unique characteristics of interactions between technology, industry, policy, markets and society".

A research field that analyses this interplay to understand sectoral and industrial transformation processes is transition studies. This multidisciplinary field has developed intensely over the past 20 years and has been applied in a broad variety of sectors, such as energy, water, food, transport and public health (Heiberg et al., 2022). The essence of the theory lies in the alignment of actors, technologies and institutions into socio-technical configurations "that work" (Rip & Kemp, 1998). This implies that when the core configuration is well-aligned and highly institutionalized, a sector will tend to follow constrained trajectories for a long time before a deep structural reconfiguration of the socio-technical system can occur (Heiberg et al., 2022). The introduction of novel (sustainable) technologies to the market through a process of niche development can

[1] This study does not consider fourth-generation biokerosene, which is recognized by a few researchers (Doliente, 2020).

eventually lead to the replacement of dominant (polluting) technologies (Schot & Geels, 2008). Developed technological niches, which are "protected spaces that allow nurturing and experimentation with the co-evolution of technology, user practices and regulatory structures", can trigger this systemic regime change when they gain internal momentum while 'windows of opportunity' arise (Schot & Geels, 2008). During such a transition phase, the actor's previously dominant field logic is being contested by new field logics fighting for legitimacy (Fuenfschilling & Truffer, 2014). Field logics comprise coherent bundles of institutional logics, which are "socially constructed (…) values, beliefs and rules by which individuals produce and reproduce their material subsistence, organize time and space and provide meaning to their social reality" (Thornton & Ocasio, 1999). A shift in field logic results in corresponding changes in technological choices, actors' strategies or problem focus within the socio-technical system. The socio-technical system of aviation fuels in the Netherlands has evolved over an extended period, with well-established institutional structures that have played a pivotal role in shaping the production, distribution and utilization of aviation fuels within the country (Shell, 2022). This thesis seeks to understand how and under what circumstances technological niches of SAF can reconfigure the interlinked social and technical elements of this deep structure. The following research question is therefore formulated:

How and under what conditions can technological niches of SAF reconfigure the regime of the Dutch socio-technical system of aviation fuel?

A method that allows for assessing (dis-)alignments among actors, technologies and institutions in transition processes is the recently proposed Socio-Technical Configuration Analysis (STCA) (Heiberg et al., 2022). This semi-quantitative methodology captures and visualizes reconfigurations within socio-technical systems over space and time (Heiberg et al., 2022). It enables the identification of key elements of socio-technical configurations based on textual analysis of actor statements (Miörner et al., 2022). In practical terms, the method was utilized to create networks of the Dutch socio-technical system of aviation fuel, illustrating how technological and institutional concepts related to the incumbent configuration of conventional kerosene and the configurations of SAFs (dis-)aligned over time. The visual information provided by the networks, combined with the ability to analyse the underlying relational dataset offered by this STCA method, enables a dynamic approach to addressing the research question of this study. It allows for identifying, for each SAF, the factors and processes that led to its technological niche either reconfiguring the socio-technical regime, persisting as a niche away from the regime, or ceasing to exist. Furthermore, the STCA method was employed to construct networks demonstrating the evolution of actors and their field logics across time, providing deeper insights into how they influenced the trajectory of the niches. The analysis identifies core reconfiguration trends since 2006, delineating three distinct phases drawn from distinct critical moments.

This study is the first to apply STCA through a combination of approaches. It involves applying the method in the manner proposed by Heiberg et al. (2022), using technological and institutional codes as 'mapped variables' and two distinct paradigms as 'complementary variable'. Additionally, the study employs the institutional logics approach, using actors as 'mapped variable' and clusters of field logics as 'complementary variable' (Fuenfschilling & Truffer, 2014). By doing so, this study advances the application of STCA and contributes to strengthening the methodology's credibility and versatility in the realm of transition studies. Exploring SAF goes beyond merely understanding the structure of actors and concepts that comprise the technological niches. This research aims to contribute by investigating the extent to which STCA can serve as a valuable methodological tool for gaining insights into the conditions under which a technological niche can instigate regime shifts, considering technological and institutional concepts as well as actors and their field logics. Furthermore, this research also holds societal relevance. Understanding the dynamic nature of socio-technical alignment processes within the Dutch socio-technical system of aviation fuel is imperative to effectively formulate innovation policies aimed at transformation and identify successful transformative policy-mixes for the country's aviation sector. Not only effective policy, but also further legitimization of the different SAFs can be achieved through this analysis, both contributing to the sustainable transition towards a carbon-neutral aviation sector in the Netherlands by 2050.

This study is structured as follows. The theory section introduces various perspectives on socio-technical transitions, discusses theoretical concepts and reflects on existing literature. This section is closed by exemplifying the applicability of the selected case for this research by integrating it with theoretical concepts. The methodology describes the usefulness of STCA, the methods of data collection and analysis, followed by an explanation how the research quality is ensured. The results section starts with outlining the sector's historical development before the relational data and networks are analysed. The thesis ends with a conclusion answering the research question, followed by a discussion of limitations and theoretical implications and a suggestion for future research.

2. Theory

This section introduces the theoretical perspective on socio-technical transitions. It starts with unravelling the origins of this theory and its interconnectedness with other prominent theories. Then, the pivotal role of technological niches within socio-technical regimes is discussed. This is followed by an exploration of the neo-institutional approach, focusing on the significance of key concepts such as organizational fields and institutional logics. Institutional logics can provide deeper insights into the overall factors driving the influence of specific field logics on actor strategies and their impact on shaping the development of sectors (Fuenfschilling & Truffer, 2014). This section ends with integrating theoretical concepts with the 'Dutch aviation fuel case'.

2.1 Socio-technical transitions

Following Heiberg et al. (2022), transitions can be understood as "emerging socio-technical configurations, whose social and technical elements get more aligned and institutionalized as they mature and start to reshape previously dominant configurations in the field". That is, sectoral and industrial change processes are "reconfigurations of technological and institutional elements that align into novel socio-technical configurations" (Heiberg, 2022). This is contrary to a neoclassical viewpoint, that attributes sectoral and industrial change to investments in research and human capital (Heiberg, 2022).

The roots of socio-technical theories can be traced back to the 1980s when Evolutionary Economics (EE) and Science and Technology Studies (STS) started challenging the dominant notion of technological determinism (Miörner et al., 2022). In their 1982 work, Nelson and Winter proposed that technological change is contingent upon particular cognitive routines within professional communities, guiding innovations into specific trajectories known as 'technological regimes', while also being shaped by the socially constructed selection environment of markets and institutional structures (Miörner et al., 2022). On the same note, Dosi (1982) underscored the significance of technological paradigms, defined as a "pattern of solution to selected technoeconomic problems (…)", which encompass not only the technological artifacts to be used but also the set of heuristics that guide their usage (Dosi, 1988). Additionally, Dosi considered paradigms as a structural force directing technological change (Heiberg, 2022). Theorists within the STS tradition moved beyond this perspective by underlining the social construction of technological systems, conceptualizing them as 'seamless webs' of interrelated technological, social and institutional elements (Hughes, 1983; Hughes, 1987). Sociologists contended that networks of mutual dependencies are established by scientists, users, policy makers and societal groups besides engineers and firms, facilitating certain trajectories of technological development (Geels & Kemp, 2007). They thereby extended the term 'technological transition' to 'socio-technical transition' to incorporate the social and institutional complexities (Bijker, 1995). Building on the seamless web approach, Geels & Kemp (2007) argued that a socio-technical system can be described as "a cluster of elements, involving technology, science, regulation, user practices, markets, cultural meaning, infrastructure, production and supply networks".

A fundamental concept in the realm of transition studies is that long-established configurations within these socio-technical systems display strong path dependencies, substantial resilience and stability over extended periods of time (Kemp et al., 1998). This is often ascribed to the existence of socio-technical regimes (Kemp et al., 1998; Markard & Truffer, 2008; Smith et al., 2010). These regimes can be perceived as a set of highly institutionalized formal and informal rules that have co-evolved with technologies and actor networks, becoming ingrained in practices and routines over time (Fuenfschilling & Truffer, 2014; Fuenfschilling, 2019). Within literature, notably within the framework of the multi-level perspective (MLP), this regime is referred to as the 'deep structure' of a socio-technical system (Geels, 2011). Within most sectors, this structure appears to be semi-coherent, uniting a diverse range of actors, technologies and institutions into various socio-technical configurations “that work” (Fuenfschilling & Truffer, 2014; Kemp et al., 1998). To transform the socio-technical regime, it is imperative to change the underlying rulesets and to either undo or reconfigure the interconnected social and technical elements that comprise and stabilize its core configurations (Heiberg, 2022). This systemic regime change can be triggered through the development of technological niches, which are “protected spaces that allow nurturing and experimentation with the co-evolution of technology, user practices and regulatory structures” (Schot & Geels, 2008). According to strategic niche management (SNM) scholars, these niches serve not only to test the design of the technology, but also to facilitate mutual articulation and alignment between technology, demand and broader societal issues, such as sustainable development (Schot & Geels, 2008). That is, they act as building blocks for broader, interrelated social and technical changes towards sustainable development. In early SNM research, it is suggested that the selective introduction of novel (sustainable) technologies to the market through a process of niche development can eventually lead to the replacement of dominant (polluting) technologies (Schot & Geels, 2008). New technologies often struggle, however, to overcome the 'valley of death' that exists between research and development and market introduction. Therefore, Kemp et al. (Schot & Geels, 2008) identified three internal processes crucial for the successful development of a technological niche into a market niche (a niche in which technology design and user demands have become stabilised) and ultimately triggering a regime shift.

Technological niches, being emerging, innovative socio-technical configurations, gain internal momentum when the socio-technical alignment of diverse learning processes leads to a stable configuration and when expectations and visions become less ambiguous and gain broader acceptance (Bui et al., 2016; Geels, 2011; Schot & Geels, 2008). Momentum also builds when actors facilitate social network expansion by providing legitimacy and resources to the niche innovations (Geels, 2011; Schot & Geels, 2008). However, apart from bottom-up processes of niche expansion, destabilization of the existing regime is necessary for creating 'windows of opportunity' for the novel niche innovations to break through (Geels, 2011). This destabilization occurs due to external processes in the broader context at the landscape level, for example through political, macroeconomic, cultural or climate-related developments or scarcity of specific resources (Geels, 2011). A transition is ultimately conceived of as a shift from one dominant socio-technical configuration to another, i.e. from one regime to another (Fuenfschilling & Truffer, 2014). *Figure 1* demonstrates the mutual link up and reinforcement of processes across multiple dimensions and levels.

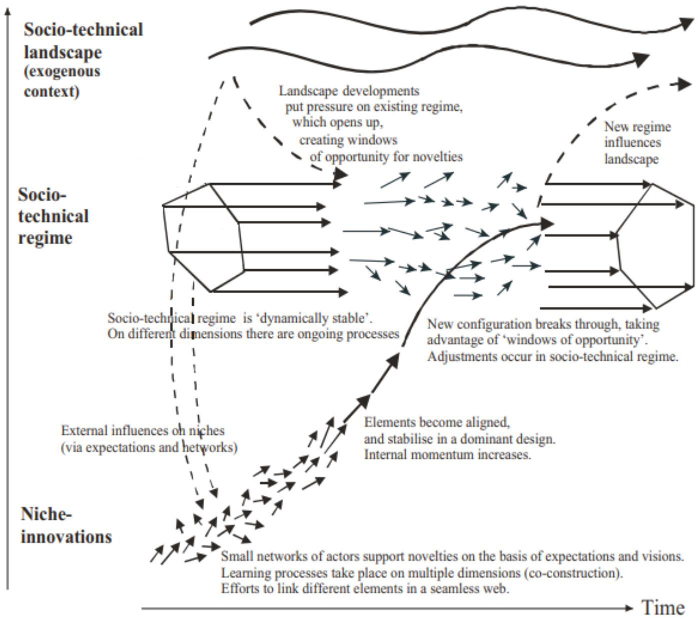


Figure 1: Multi-level perspective on socio-technical transitions (Illustration retrieved from Geels (2011))

2.2 Organizational fields and field logics

The neo-institutional point of view on socio-technical transitions regards transitions as reconfigurations in organizational fields (Fuenfschilling, 2019). Fuenfschilling and Truffer (2014) argued that this perspective offers a more flexible and less rigid conceptualization of socio-technical change processes compared to the traditional categorization of regime, niche and landscape structures (Heiberg et al., 2022). Organizational fields can be understood as "the aggregate of all organizations active in a field of institutional life" (Heiberg et al., 2022). How strong or weak a regime is in guiding actor strategies depends, in part, on the amount of opposing field logics that exist in the respective organizational field (Fuenfschilling & Truffer, 2014). Field logics comprise coherent bundles of institutional logics, which are "socially constructed (…) values, beliefs and rules by which individuals produce and reproduce their material subsistence, organize time and space and provide meaning to their social reality" (Thornton & Ocasio, 1999). Given the assumption of bounded rationality among actors, field logics serve as guiding principles that offer specific rationalities, set the rules of the game and direct attention towards particular problems and solutions (Fuenfschilling & Truffer, 2014). A shift in field logic results in corresponding changes in technological choices, actors' strategies or problem focus.

Following Fuenfschilling and Truffer (2016), the direction of a transition, whether towards a higher or lower degree, can be influenced by the extent to which a field logic is institutionalized within an organizational field. A strong regime is defined by a well-aligned and deeply institutionalized socio-technical configuration, that responds to a single and generally undisputed dominant field logic (Heiberg et al., 2022). This regime not only maintains coherence and stability, and thus wields substantial power over the behaviour and cognition of actors, it also directs the trajectory of socio-technical system development (Fuenfschilling & Truffer, 2014). The more certain actors align with the prevailing field logics, the more inclined they are to endorse merely incremental changes in the regime's transition. These are often the more resourceful and prestigious actors in the field (Fuenfschilling & Truffer, 2016). At the opposite end of the spectrum, a weak regime is distinguished by multiple poorly aligned socio-technical configurations, where various field logics compete for legitimacy, thereby undermining overall structuring of the field (Fuenfschilling & Truffer, 2014; Heiberg et al., 2022). This scenario often arises during a transition phase, where a previously dominant field logic is being contested by a new one, leading to multiple processes of both institutionalization and deinstitutionalization of old and new elements (Fuenfschilling & Truffer, 2014). Actors who align with more peripheral field logics then typically advocate for more radical trajectories. They will, however, encounter challenges in securing resources and material investments, thus facing difficulties in shaping the direction of sectoral development in their favour (Fuenfschilling & Truffer, 2014).

Considering that a transition of a socio-technical system can be understood as a change in prevailing field logics, it is imperative to recognize the significance of power and agency in these socio-technical transitions (Fuenfschilling & Truffer, 2014; Jolly & Raven, 2018). Agency, in this context, is characterized by the institutional work aimed at (de-)institutionalizing the institutional logics of a system (Fuenfschilling, 2014). Jolly & Raven (2018) state that "a deeper understanding of shifting power relations between actors and their effort to engage in institutional work is considered important for developing a systematic understanding of transitions". Understanding the strategies and interests of powerful actors such as incumbent firms and policy makers is crucial, as actors play a mediating role between technologies and institutions, the two pillars of a socio-technical system (Jolly & Raven, 2018). From a neo-institutional point of view, one could reflect on the work of SNM scholars by questioning whether the breakthrough of a technological niche is, apart from internal processes and windows of opportunity, moreover dependent on the institutional work applied to foster or hinder it, as well as on the power relations of institutionalized actors in the field.

2.3 Bridging theory with the Dutch aviation fuel case

The Dutch aviation fuel case centres on the socio-technical system of aviation fuel in the Netherlands. In line with the approach of Geels and Kemp (2007), this study considers the Dutch socio-technical system of aviation fuel as a system that includes technology, science, regulation, user practices, markets, cultural significance, infrastructure, production and supply networks revolving around aviation fuel in the Netherlands. This socio-technical system has evolved over an extended period, with well-established institutional structures and configurations displaying strong path dependencies that shaped the production, distribution and utilization of aviation fuels within the country (Shell, 2022). However, this system, as most socio-technical systems, is subject to what Fuenfschilling (2014) refers to as extreme events, exogenous developments and the associated changes in institutional logics. The emergence of various technological niches of SAF within the Dutch socio-technical system of aviation fuel poses a potential challenge to the deeply institutionalized regime-maintaining logics, making it a suitable case for examining how and under what circumstances these niches can reconfigure the system's deep structure.

These SAFs can be classified into two primary categories (CE Delft, 2017). The first one being synthetic kerosene, which is created using electricity, water and carbon dioxide captured from the atmosphere (CE Delft, 2017). Biomass-based kerosene, known as biokerosene, is the second primary category, with three distinct generations having evolved over time (Nanda et al., 2018). First-generation biokerosene consists of ethanol derived from food crops, such as corn, soybeans, palm oil and rapeseed (Stimular, n.d.). Second-generation biokerosene involves agricultural residues, such as straw, wheat bran or animal manure, as well as waste streams from the (food) industry, such as used cooking fat and residual vegetable oil (Stimular, n.d.). A third-generation biokerosene utilizes (micro)algae as a raw material to produce sustainable kerosene (Stimular, n.d.)

It is not the fuel types themselves, but rather the socio-technical configuration of these SAFs that can be considered technological niches (Heiberg et al., 2022). This is apparent from all four SAFs having been supported by a small network of actors and institutions in a protected space apart from the established regime, where research and development, local experiments and regulatory learning take place (Schot & Geels, 2008). These technological niches cannot be labelled as radical because the SAFs were not nurtured with the intention to entirely overthrow the regime, but rather to be drop-in technologies that are ultimately compatible with existing infrastructure, airplane engines and safety protocols.

3. Methodology

This section delves into the methodological approach used to answer the research question. It starts with presenting the research design and emphasizing the usefulness of the method employed in this research. Then, a detailed overview of the data collection process is provided, followed by an in-depth exploration of the method used for data analysis. Finally, the research validity and reliability are discussed.

3.1 Research design

So far, most transition studies have leveraged historical or qualitative case studies to understand the intricate and systemic nature of socio-technical transformations (e.g., Ernst et al., 2016; Geels, 2002; De Haan & Rotmans, 2011). While these enable a detailed reconstruction of the dynamic realignment processes between technological and institutional elements, they prove inadequate when seeking to capture complex interaction patterns and interdependencies between the entities that conjointly form emergent properties within a transformation process. A recently proposed methodology that enables the graphical representation of an organizational field and the dynamics of its institutional logics, is Socio-Technical Configuration Analysis (STCA) (Heiberg, 2022). This semi-quantitative methodology builds on and extends the established Discourse Network Analysis (DNA) method and allows to "empirically study configurations as bundles of entities related through socio-technical linkages" (Heiberg, 2022; Heiberg et al., 2022). It enables mapping configurations of actors and concepts (such as technologies, governance modes and values), as well as the alignments among them and the strength of their linkages at different points in time and in different spatial and scalar contexts (Heiberg, 2022). The method thereby allows to explore the emergent properties of socio-technical configurations, the mechanisms behind reconfiguration processes and the degree of institutionalization of different actors and concepts in a sector or industry (Heiberg, 2022).

More specifically, STCA can be employed to analyse diverse beliefs, arguments or stances held by actors on a specific topic. These 'advocacy coalitions' are operationalized through 'actor congruence networks', where connections between actors are formed based on their congruent statements regarding a particular concept. The theoretical concept of institutional logics serves as a foundation for assessing the value dispositions of various actors. The networks illustrate the presence of multiple field logics that actors adhere to, delineating clusters of actors who share approximately the same perspectives and beliefs. In this manner, STCA aids in providing a deeper understanding of the impact of actors and their field logics on both the dominant socio-technical configuration (regime) and the emerging socio-technical configurations (technological niches).

This method can also be utilized to study prevalent 'storylines' in public discourse (Heiberg et al., 2022). Concepts are aggregated into 'concept congruence networks', which illustrate interconnections between concepts that are present in the discourse within a particular organizational field. Heiberg et al. (2022) state that "if two concepts are uttered in tandem by the same actor(s), this implies some degree of ideological and intrinsic compatibility between them. Congruent supportive or obstructive statements around several concepts can then be interpreted as coherent storylines." Shifts in both and established socio-technical configurations can be visualized by mapping actor statements around particular technological and institutional concepts as relational structures. Both the networks and the qualitative nature of the data allow for gaining better insight into the processes that underlie the integration of emerging socio-technical configurations (technological niches) with the established configuration (regime).

Discourses are perceived as a relevant proxy measure for identifying patterns, dynamics and strategies through which socio-technical configurations (dis-)align over time (Heiberg, 2022). Actors advocating for or against a particular technological solution do not merely assess its performance, but also weigh its broader implications across social, political, economic, ecological or spatial dimensions (Geels & Verhees, 2011). Particularly in critical moments, when crises occur or when a sector contends with strong endogenous development challenges, actors will be compelled to publicly voice their opinions on how to solve the imminent challenges or underscore the necessity for accelerating innovation (Miörner et al., 2022). Within these periods of intense external pressures and heated discourse activity socio-technical transitions or major reconfiguration processes tend to gain more momentum (Heiberg, 2022; Yuana et al., 2020). The STCA method segments the discourse into phases delineated by the occurrence of these critical moments. This enables identification of configurational shifts across various phases of the discourse in separate networks. The critical moments in this research are identified by exploring the sector's historical development and then verified against the critical moments described in Geels' (2011) theory. Geels (2011) notes that the destabilization of a socio-technical regime can occur due to critical moments as crises, resource scarcity, political dynamics and macroeconomic, cultural and climate-related developments. In this thesis, three critical moments are discerned, delineating three distinct phases in the evolution of SAFs within the Dutch socio-technical system of aviation fuel: the energy crisis resulting in the indication by the International Air Transport Association (IATA) of soaring oil prices to extreme heights in 2006, a shift in political ideology in 2010 and the ratification of the Paris Agreement in 2016.

The Dutch socio-technical system of aviation fuel offers a compelling case study from a methodological perspective, given the emergence of various socio-technical configurations of SAF that can potentially integrate with the established, highly institutionalized configuration of conventional kerosene. This case study allows for a systematic exploration to comprehend how actors from unrelated fields employ strategies to bridge and align initially incompatible technological and institutional elements, thereby enabling the effective application of the STCA method. This research specifically centres on SAFs, excluding other alternative forms of flying such as electric flying or hydrogen gas-powered flying. These alternatives are widely considered to be impossible for long-distance flights, serving instead as potential alternatives for short distances in the distant future when technology is expected to be more advanced (Van Uffelen, 2018). Given the urgency of meeting climate goals by 2030 and 2050, these alternative forms of sustainable flying fall outside the scope of this Dutch aviation fuel case. While the scope of the case is confined to the Netherlands, it acknowledges the possible international influence on this Dutch system. For instance, top-down regulations from international bodies such as the European Parliament may impose restrictions on aviation fuel, directly impacting regulations in the Netherlands and thus the socio-technical system of aviation fuel within the country.

3.2 Data collection

In this study, connections between actors and concepts were discerned from actor statements recorded in Dutch public newspapers. These statements were extracted from a subset of articles sourced from the Nexis Uni database. The use of this online newspaper repository is common in STCA studies, primarily because its extensive database offers publicly available legal, governmental and business documents from journals, newspapers articles, professional magazines and industry reports (Miörner et al., 2022). Furthermore, Nexis Uni provides document stocks spanning extended periods, allowing for the reconstruction of long-term developments within the discourse of the selected organizational field. The selection of relevant articles was based on a search string designed to encompass a comprehensive representation of the discourse concerning the Dutch socio-technical system of aviation fuel. Crafting such an inclusive search string was an iterative process and relied on the utilization of relevant keywords.

Filtering on ‘Dutch National Newspapers’ was deemed appropriate for this research, as relevant actor statements within this broad, national discourse are typically voiced in these national papers, rather than solely in journals, magazines or regional newspapers.[2] Moreover, regional newspapers often pose practical issues as they frequently duplicate content from the national papers. The time frame 2006 to 2023 was considered appropriate, as discussions regarding alternative aviation fuels did not arise before 2006. Eventually, the optimal search string had to yield a manageable number of articles for coding, exhibit consistent development over time and demonstrate relevance in content. Appendix A provides an overview of the search string trials, the amount of resulting articles with their time trend and the evaluation of each trial.

Various search terms revolving around SAFs were first tried in combination with the terms *'luchtvaart'* and '*vliegsector'* to reduce the number of articles, yielding an excessive amount of articles that demonstrated little relevance in content. The notation 'w/s' was employed to find terms between brackets approximately in the same sentence and the asterisk symbol '*' was used to find variations of some terms included. In subsequent trials, 'atleast' was utilized to find search terms between brackets a minimum number of times within a document. The sample of articles started to yield improved results, thereby providing a more accurate representation of the ongoing public discourse, after keywords related to conventional aviation fuel, such as *'(fossiel* w/s brandstof*)'*, were also incorporated. During the evaluation of the sampled articles, new search terms were identified and deemed relevant to include in the search string. This iterative process involved continuously adding keywords from the public debate until further additions did not significantly enhance the comprehensiveness of the article sample. Attempts to refine results by adjusting parameters, such as changing from 'atleast3' to 'atleast4', were carefully monitored to ensure that relevant articles were not being excluded, avoiding filtering out of significant parts of the discourse. This was, for instance, the case with trials 9 and 10, where not only a substantial number of relevant articles were omitted, but there was also an insufficient number of articles for coding remaining after manual filtration of irrelevant articles. Therefore, trial 8 was selected as the most comprehensive search string for this research (refer to *Table 1* for its evaluation).

[2] 'Dutch National Newspapers' comprise the following newspapers: Algemeen Dagblad, De Volkskrant, De Telegraaf, Het Parool, NRC Handelsblad, NRC, Reformatorisch Dagblad, Nederlands Dagblad, Trouw, Het Financieele Dagblad, Metro, Spits.

Table 1: An overview of the search string, the amount of resulting articles with their time trend and the evaluation of trial 8 (refer to Appendix A for an overview of all trials)

Search string	**Results**	**Time trend**	**Evaluation**
atleast5(kerosine or vliegtuigbrandstof or (brandstof w/s vlieg*) or (brandstoffen w/s vlieg*) or (fossiel* w/s kerosine) or (fossiel* w/s brandstof*) or (aardolie w/s kerosine) or (brandstof* w/s aardolie) or (ruw* w/s olie w/s kerosine) or (ruw* w/s olie w/s brandstof*) or biokerosine or biobrandstof* or (synthetisch* w/s kerosine) or (synthetisch* w/s brandstof*) or (duurza* w/s kerosine) or (duurza* w/s brandstof*) or (biologisch* w/s kerosine) or (biologisch* w/s brandstof*) or (alternatie* w/s kerosine) or (alternatie* w/s brandstof*) or kunstkerosine or (milieuvriendelijk* w/s kerosine) or (milieuvriendelijk* w/s brandstof*) or (hernieuwba* w/s kerosine) or (hernieuwba* w/s brandstof) or (elektrisch w/s kerosine) or (elektrisch w/s brandstof) or (elektrisch w/s vlieg*) or (waterstof w/s kerosine) or (waterstof w/s biobrandstof*) or (schone w/s kerosine) or (schone w/s brandstof*) or (circulaire kerosine) or (circulaire brandstof*) or (groen* w/s kerosine) or (groen* w/s brandstof*) or (SAF w/s duurza*) or (sustainable aviation fuel)) and atleast3(luchtvaart* or vliegsector or vliegen or luchthaven or vliegtuig)	439		Articles demonstrate acceptable relevance in content Manageable amount of articles for coding after manual filtration Acceptable comprehensiveness of search string Consistent development of articles over time

The 439 sampled articles were then filtered manually to eliminate irrelevant and duplicate articles. The final dataset consisted of 320 articles, meaning 73% of the initial sampled articles were analysed. *Figure 2* illustrates the distribution of analysed articles by year, as well as the distinction of the three developmental phases. The figure also demonstrates that after each critical moment (red line), there is a peak in the number of published articles and thus in media discourse activity revolving around Dutch aviation fuel.

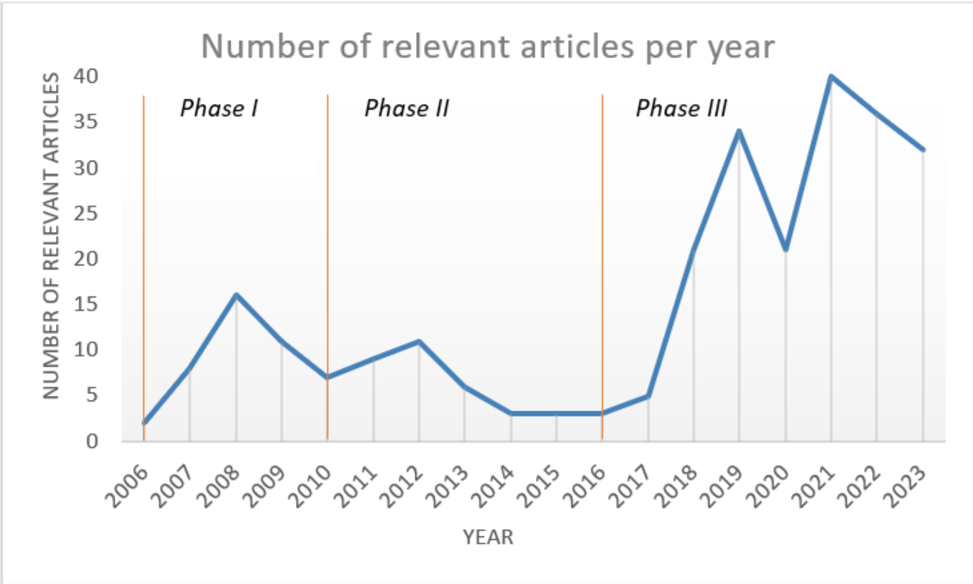


Figure 2: Distribution of analysed articles by year

Desk research, primarily through internet searches, was utilized as a secondary method of data collection to establish an initial understanding of the aviation industry and the historical development of SAF within the sector. Moreover, additional attributes for actors, projects and collaborations were gathered to supplement information not included in the dataset.

3.3 Data analysis

The approach to understanding the field dynamics and (re-)alignment processes involved a systematic analysis that traced the logics embedded in the statements made by actors within the sampled newspaper articles. The identification of actors and concepts unfolded through a qualitative and recursive coding process using the qualitative content analysis software NVivo. Given that the alignment of actors, technologies and institutions into socio-technical configurations "that work" forms the core of theory on reconfigurations of socio-technical systems, these had to serve as the foundation for the coding scheme in this research. Therefore, a classification was made with 'Actors' on one hand and 'Concepts' ('Technologies' and 'Institutions') on the other.

To ensure a well-balanced, high-quality coding scheme, this research adopted an abductive approach to coding. There was continuous iteration among data, emerging patterns and existing theory, to develop the final coding scheme (Miörner et al., 2022). Within this trial-and-error approach, creating regular network visualizations has been proven useful for receiving feedback of the quality of the data and the coding scheme (Miörner et al., 2022). To capture the core of the field, comparing network visualizations with theoretical or empirical expectations aided in determining whether to persist with coding, adapt the choice of data sources or consider modifications to the coding scheme.

In the coding process, different types of actors were identified, such as 'Airlines', 'Environmental Organizations' and 'Knowledge Institutions'. Moreover, a distinction was made within the coding scheme to categorize concepts originating from 'Technologies,' covering 'Fuel Types' and 'Infrastructure Types', as well as concepts arising from 'Institutions,' including 'Governance Arrangements' and 'Values', along with two additional concepts 'Financial Incentives' and 'Reports', which affect both technological and institutional choices. More specifically, these concepts could be coded within two distinct paradigms: the 'Conventional

Paradigm' (concepts followed by '(c)') and the 'Sustainable Paradigm' (concepts followed by '(s)'). The 'Conventional Paradigm' encompasses technological and institutional elements related to fossil-fuel-based aviation fuel, representing rather traditional modes of thinking, operation and problem-solving. The 'Sustainable Paradigm' covers technological and institutional elements related to SAF, representing ways of thinking, working and problem-solving that focus on sustainable development within the Dutch aviation sector. For each code it was indicated what actor(s) made the statement and whether the concept was referenced positively (supportive) or negatively (obstructive).

An exemplary representation of how an actor's statement was coded:

"The main disadvantage of synthetic kerosene is that the production of hydrogen and the capturing of CO2 from the air require a significant amount of green energy. Green energy that is unfortunately (still) not available, states nature conservation and environmental organization Natuur & Milieu."[3]

First, the statement was coded under the actor making the statement 'Natuur & Milieu'. Secondly, it was coded negatively (-) under the concept 'Synthetic Kerosene (s)', due to the actor's reference to a disadvantage of synthetic kerosene. Thirdly, the statement was coded positively (+) under the concept 'Values (s)' as the actor expressed a positive stance towards sustainable aviation by noting the unfortunate unavailability of green energy in the Dutch aviation sector.

Once the coding process was finalized, the co-occurrences of codes were exported as a two-mode data matrix from NVivo, with rows and columns denoting actors and concepts, respectively. Three of these co-occurrence matrices (one for each developmental phase) were then transferred to the programming language R and further processed through an R script to first generate three unweighted one-mode concept congruence matrices.[4] *Figure 3* illustrates how the relational information from the two-mode data was condensed into a one-mode configuration. Within the two-mode actor-concept configuration, actors and concepts are portrayed as directly connected nodes, indicating the actors' references to particular concepts. Here, the actors act as the 'associating variable', as they co-mention concepts in their statements or regularly combine concepts in innovation activities. The concepts themselves serve as the 'mapped variables' and are mapped in the concept congruence networks (Miörner et al., 2022). A link between two concepts is established when an actor conjointly refers supportively or obstructively to the concepts, i.e. the two concepts are co-mentioned congruently. Appendix B provides an overview of the final coding scheme used in this study, including additional information on actor and concept codes where deemed necessary.

[3] This statement was originally made in Dutch in Financieele Dagblad (Schenk, 2022).
[4] The R scripts used in this study were retrieved from the STCA guidebook (Miörner et al., 2022).

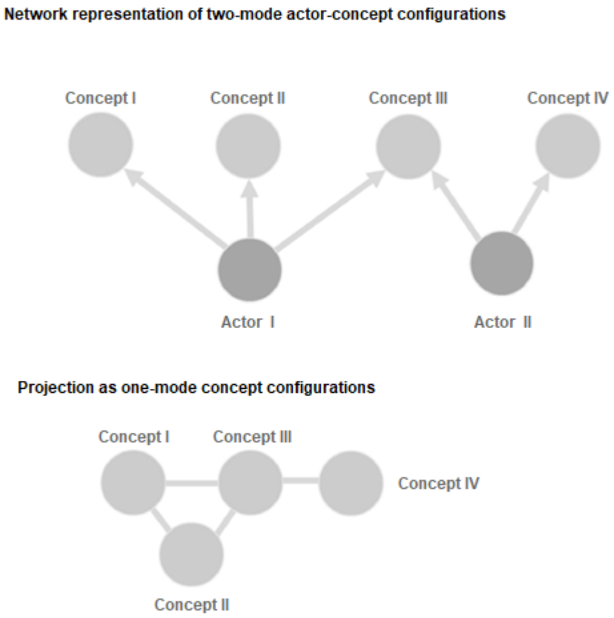


Figure 3: Two-mode actor-concept configurations condensed into one-mode concept configurations (illustration inspired by Heiberg et al. (2022))

Subsequently, the unweighted one-mode concept congruence matrices were normalized into networks containing the Jaccard similarity of the concepts (Miörner, 2022). The Jaccard similarity ‘s’ in a concept congruence network is expressing the relative overlap between two concepts:

$$s = \frac{a}{(a+b+c)},$$

$$where\ n11 = a,\ n10 = b,\ n01 = c$$

In this formula, ‘a’ denotes the number of actors that have used both concepts congruently, while ‘b’ and ‘c’ represent the number of actors that have referred to either one or the other of the two concepts. This yields a score of 0 when the two concepts have never been mentioned conjointly by any actor and a score of 1 when the two concepts were always co-mentioned. The score between 0 and 1 reflects how strongly the two concepts have been associated by the actor(s) in the articles analysed. Accordingly, a Jaccard index of 1 or close to 1 indicates a more coherent storyline than an index value close to 0.

Following the same approach, three unweighted one-mode actor congruence networks containing the Jaccard similarity of the actors were generated in R, established using the same initial co-occurrence matrices. In these networks, the concepts function as the associating variable, while the actors act as the mapped variables. These actors are mapped in the actor congruence networks, forming connections between them based on their shared reference (both supportive or both obstructive) to the same concept.

Once the data was transferred from R to the Visone software package, the concept congruence networks were first visualized (refer to simplified example in *Figure 4*). Time is the 'partitioning variable' and allowed for the creation of separate networks representing subsets of the data, aiding in the identification of configurational shifts across time (Miörner et al., 2022). Three networks were generated, each corresponding to a distinct developmental phase, encompassing both technological and institutional concepts. Incorporating the following 'complementary variables' enriched the information in the networks and enhanced their comparability (Miörner et al., 2022). Two paradigms were distinguished: blue nodes signifying concepts of the 'Conventional Paradigm' and green nodes representing concepts of the 'Sustainable Paradigm' (Heiberg et al., 2022). The nodes were varied in shape to indicate the type of concept being depicted. Furthermore, the width of the links (edges) between concepts was based on their Jaccard index, reflecting the strength of their mutual alignment. Multiple concepts that were strongly aligned with each other thereby indicated a socio-technical configuration with a coherent storyline.

The maps were structured as 'radar plots' to distinguish between 'central' and more 'peripheral' concepts, offering an indication of the degree of institutionalization of particular concepts within the field (Heiberg, 2022). A concept that was co-mentioned congruently with numerous other concepts, thereby indicating its central role in the discourse within a specific time period, had a high 'degree centrality' score, represented by its central position in the radar plot. The degree of institutionalization was also contingent upon the number of actors who have endorsed a certain concept in a given period. The more different actors referenced a concept in their statements, the more prevalent that particular concept was. Within the networks, the number of actors utilizing a concept was depicted by the size of each node.

Lastly, the overall composition of the concept congruence network revealed whether and how strongly different socio-technical configurations were aligned (Heiberg et al., 2022). Illustrated in *Figure 4* is the gradual alignment and integration of the peripheral configuration of nodes, representing an emerging socio-technical configuration, with the established regime structure, eventually leading to a reconfiguration into a new socio-technical regime (Heiberg et al., 2022).

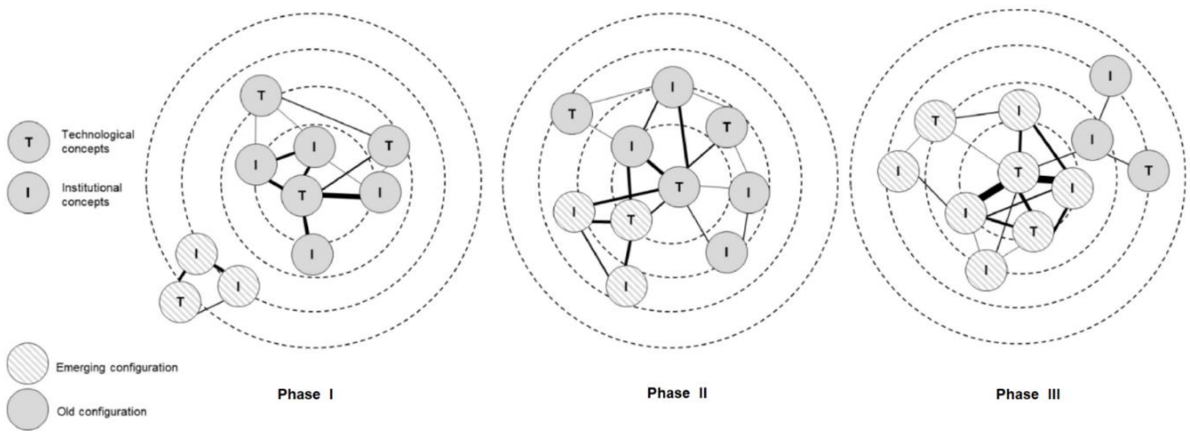


Figure 4: Simplified example of concept congruence networks, illustrating a reconfiguration into a new socio-technical regime over three phases (illustration retrieved from Heiberg et al. (2022))

Similarly, three actor congruence networks were visualized, depicting different actors within the organizational field. The nodes were varied in colour to denote the type of actor being depicted. The width of the edges between actors was again based on the Jaccard index. Additionally, the degree centrality was reflected by the number of other actors that an actor has shared at least one concept with in a congruent manner. The size of each node reflected the total number of statements the actor made within a specific time period. Furthermore, the overall composition of the networks was visualized in separate networks by outlining clusters of actors, signifying the different field logics they adhere to. This study identified four distinct field logics and two combinations of those logics, derived from statements made by actors in the sample of articles. Each actor was assigned to one or more field logics in Excel and this was subsequently visualized in Visone through the clustering function. *Table 2* demonstrates the operationalization of the discerned field logics.

Table 2: Field logics adhered to by actors within the organizational field

Field logics	Description
Defensive Logic	Statements revealing actor's predilection towards the Conventional Paradigm. Actors adhering to this logic are reluctant for a shift towards a more Sustainable Paradigm and/or state that the Conventional Paradigm will maintain its superiority in the field (especially in the short term).
Critical Logic	Statements revealing actor's criticism towards the Conventional Paradigm. Actors adhering this logic aim for a shift towards a more Sustainable Paradigm (without explicitly stating this should be achieved by investing in SAF) and/or state that the Conventional Paradigm is losing its superiority in the field.
Revolutionary Logic	Statements revealing actor's call for the comprehensive transformation of societal 'deep structures' that shape production and consumption. Actors adhering to this logic present achieving sustainability as requiring fundamental and revolutionary change. They prioritize replacing the growth focus with 'de-growth' to combat over-consumption and therefore do not consider SAF as the solution towards a more Sustainable Paradigm.
SAF Supportive Logic	Statements revealing actor's support towards the production, development and/or diffusion of biokerosene and/or synthetic kerosene. Actors adhering to this logic support SAF without explicitly stating that they are/are not critical towards the Conventional paradigm.
Combination of Defensive Logic and SAF Supportive Logic	Statements revealing actor's predilection towards the Conventional Paradigm while revealing their support towards the production, development and/or diffusion of biokerosene and/or synthetic kerosene. Actors adhering to this combination of logics are reluctant for a shift towards a more Sustainable Paradigm and/or state that the Conventional Paradigm will maintain its superiority in the field (especially in the short term). However, they view investing in SAF as an ancillary matter that poses no harm and/or consider it advantageous for prospective applications.

Combination of Critical Logic and SAF Supportive Logic	Statements revealing actor's criticism towards the Conventional Paradigm while revealing their support towards the production, development and/or diffusion of biokerosene and/or synthetic kerosene. Actors adhering to this combination of logics aim for a shift towards a more Sustainable Paradigm by investing in SAF and/or state that the Conventional Paradigm is losing its superiority in the field because of SAF.

In addition to evaluating the created networks, descriptive statistics was utilized to further analyse the underlying relational dataset. This was useful to gain more context regarding both the identified technological niches and their configurational shifts, as well as the identified actors and their field logics.

3.4 Research quality

Validity and reliability were ensured to uphold research quality (Bryman, 2012). Maintaining validity involves mitigating the influence of external factors that may cause variation in the results, ensuring accurate measurement of what is intended to be measured (Middleton, 2023). This study's methodology was founded upon the STCA guidebook, crafted by the original creators of the STCA methodology (Miörner et al., 2022). By adhering to the guidelines of this comprehensive guidebook, potential biases and inconsistencies were minimized, thereby fortifying the internal validity of this research. Although this research did not perform inter-coder reliability checks - where multiple researchers independently code the data to verify consistency and agreement - the coding scheme underwent examination and discussion with the supervisor to negate researcher bias, thereby ensuring internal validity. Furthermore, data triangulation was used as a research strategy to reinforce validity through the convergence of information from different sources.

Reliability in research refers to the consistency and stability of findings or measurements (Middleton, 2023). It signifies the degree to which a study's results can be replicated to produce similar outcomes under consistent conditions. To facilitate research replication, this study aimed to meticulously describe how data was collected and analysed and ensured transparency through the documentation of the search string and coding scheme (refer to Appendix A, B and E). Additionally, leveraging publicly available software and an open database further enhanced the study's replicability and thus its reliability.

4. Results

This section starts with an overview of the historical development of SAF within the aviation sector, identifying three critical moments that justify the three developmental phases recognized in this study. Following this, the results of the STCA are discussed. For each phase, the actor congruence network and the various actor types are initially examined, followed by a detailed exploration of the field logics of those actors. Subsequently, the concept congruence network is discussed broadly before delving into an in-depth analysis of the socio-technical configurations of the different SAFs. This entails analysing, for each SAF, the factors and processes that led to its technological niche either ceasing to exist, persisting as a niche away from the socio-technical regime, or integrating with the established regime configuration.

4.1 Historical development

4.1.1 Phase I (2006-2009)

The strong increase in oil prices since 2002 due to the energy crisis had adverse effects for the aviation industry (Het Parool, 2006; Van Geuns, 2011). In 2006, IATA made a projection that jet fuel prices would remain elevated for an extended duration, which led to a growing interest in non-fossil aviation fuels (Het Parool, 2006). The issue started to attract more media attention as well as research interest when KLM CEO Leo van Wijk, who also served as the chairman of the IATA's strategic committee, articulated a strong commitment to research and development of suitable alternative fuels (Het Financieel Dagblad, 2006). He noted that KLM would play an active role in supporting this initiative. The media deemed this a rather conflicting development because, for years, van Wijk had proclaimed that non-fossil fuels would not be a viable alternative (Het Financieel Dagblad, 2006).

Even after the major drop in oil prices in 2008, due to the global economic crisis, interest in SAFs continued to grow, yet with a stronger emphasis on sustainability and environmental concerns (Van Geuns, 2011). This paradigm shift coincided, however, with rising tensions and contestations. There was a growing debate in public discourse on first-generation biokerosene, primarily fuelled by environmentalists and several political parties (e.g., Greenpeace, 2008; GroenLinks, 2008). It was contended that the cultivation of food crops specifically for biofuels led to substantial greenhouse gas emissions and deforestation (Greenpeace, 2008; GroenLinks, 2008). This practice also involved high water consumption and extensive use of agricultural land, resulting in direct competition with food production (Van Sprundel, 2012). This drove the primary focus of the Dutch aviation industry towards second- and third-generation biokerosene. An increasing number of companies in the Netherlands recognized the urgency and expressed their interest in aviation biofuels, with AlgaeLink prominently among them (Max, 2008). They signed an exclusive contract with KLM, establishing themselves as the main supplier of crude (algal) oil for a pilot-scale biofuel project (Trouw, 2008).

While the Dutch Civil Aviation Policy Memorandum of April 2009 briefly mentioned the importance of biofuels, it was in the Knowledge and Innovation Agenda later that year that the Dutch aviation sector laid out concrete partnerships and plans for biofuel development (Kraaijeveld, 2009; Rijksoverheid, 2009). These initiatives, supported by various enterprises, industry associations and knowledge institutions, aimed at achieving a significant reduction in CO2 emissions in the medium term. Two months later, the discourse gained further attention as the plans resulted in a test flight utilizing a biokerosene blend and the launch of the joint venture SkyNRG (KLM, 2009). SkyNRG, a consortium of KLM, Spring Associates and ARGOS, had the purpose of developing the market and creating a sustainable production chain for SAF (KLM, 2009).

4.1.2 Phase II (2010-2015)

The downfall of Balkenende IV and the introduction of Rutte I marked a significant shift in political ideology. A new stage commenced, as the Dutch government now started to play a more prominent role in shaping the broadened discourse on biokerosene. In 2010, the Cabinet provided a 1.25 million euro subsidy to KLM for biofuels experimentation derived from plants, which provoked immediate critique (Vroege Vogels, 2010). Milieudefensie labelled the investment a hazardous illusion, cautioning against the impact on nature and biodiversity (Vroege Vogels, 2010). After the official certification of the biokerosene supplied by SkyNRG, KLM successfully conducted the world's first commercial flight in June 2011, using a blend of 50 percent biofuel derived from used cooking oil (KLM, n.d.; Laroy, 2016). Later that year, more than 200 flights using the same blend followed and KLM entered into a Green Deal with the Dutch government regarding the future of biofuels and the implications of their Biofuel Action Plan (KLM, 2011; Verhagen et al., 2011). Furthermore, in order to make the right choices in the future, SkyNRG established a partnership with an independent sustainability board, comprising representatives from WNF, Solidaridad and the Copernicus Institute of the University of Utrecht (KLM, 2011).

Despite increased stakeholder involvement, the discourse continued to express concerns about the gradual scaling up and limited blending of jet biofuel. The primary challenge was the costs of biokerosene, being two to three times higher than those of conventional kerosene. SkyNRG assured that technological breakthroughs would bridge this price gap within the next decade (MT/Sprout, 2011). Furthermore, KLM called upon Dutch (government) businesses to join their Corporate Biofuel Program to increase demand, reduce production costs and accelerate the development of aviation biofuels (Laroy, 2016).

In the following years, production expanded under the BioPort Holland initiative (Climate Solutions, 2015). In collaboration with SkyNRG and two government ministries, the project connected Neste's biorefining supply capacity in Rotterdam with the port's transportation infrastructure and the fuel demand at Schiphol, to establish a comprehensive and robust SAF supply chain (Laroy, 2016). The government was also financially involved in a collaborative research project between Wageningen University & Research and Arke, the airline of TUI Netherlands (Luchtvaartnieuws, 2013). This initiative aimed to explore additional opportunities for biokerosene production from microalgae. They finalized the agreement despite previous critical media attention on KLM and AlgaeLink's algae project, which delivered limited results and fell short of the promised test flight using algae kerosene (Van Laar, 2012).

4.1.3 Phase III (2016-2023)

The Paris Agreement served as a pivotal moment, instigating increased awareness in the larger discourse and commitment to address the challenges posed by climate change. The agreement was signed by the EU on behalf of the Netherlands in April 2016, ushering in a new phase for various sectors in the Netherlands (Dijksma, 2016). For the aviation sector, the implementation of this agreement was carried out through the formation of the Sustainable Aviation Table, initiated by the Minister of Infrastructure and Water Management in 2018 (Duurzame Luchtvaarttafel, 2019). The Sustainable Aviation Table contained a working group on sustainable fuels, where various stakeholders collaborated to formulate objectives and shape concrete agreements for the future of SAFs (Duurzame Luchtvaarttafel, 2019). The ambitions were formalized in the Sustainable Aviation Agreement in 2019: by 2030, 14% of all aviation fuel had to be sustainable (later reduced to 6%), increasing to 100% by 2050 (Duurzame Luchtvaarttafel, 2019; Nandram, 2023; SkyNRG, n.d.). As a pragmatic approach, biokerosene was recognized as the most feasible short-term solution, with synthetic jet fuel identified for the medium term (ILT, 2021).

Flying on synthetic kerosene increasingly gained traction in public media as a viable sustainable alternative. Moreover, various studies were conducted to assess the potential for achieving climate-neutral aviation through synthetic kerosene (e.g., Gerard et al., 2019; NLR, 2021; RHIA, n.d.). In 2021, KLM undertook the first-ever commercial flight using a blend of regular fuel and synthetic kerosene, which was produced by energy partner Shell (Shell, 2021). In recent years, the discourse gained further momentum after various stakeholders voiced their plans on scaling up SAF production. By 2027, two additional factories for large-scale SAF production are set to be established in the Port of Rotterdam, along with a facility in Delfzijl and one in Amsterdam specifically for synthetic kerosene production (HyCC, 2018; Neste, 2022; Port of Rotterdam, 2021; Synkero, 2021).

Even after the Dutch government's 383 million euro subsidy for the Netherlands to become a leader in sustainable aviation, contestation persisted in the discourse (NLR, 2022; Oerlemans, 2023). Following considerable criticism from four environmental organizations, the Cabinet decided to enshrine the climate agreements into law, imposing a cap on aviation's CO2 emissions (Oerlemans, 2022; Rijksoverheid, 2023b). This step was deemed crucial to achieve the goal of zero CO2 emissions from departing international flights by 2070, as outlined in the Dutch Civil Aviation Policy Memorandum 2020-2050 (IenW, 2020b).

4.2 Socio-Technical Configuration Analysis

4.2.1 Phase I (2006-2009)

4.2.1.1 Actor congruence network

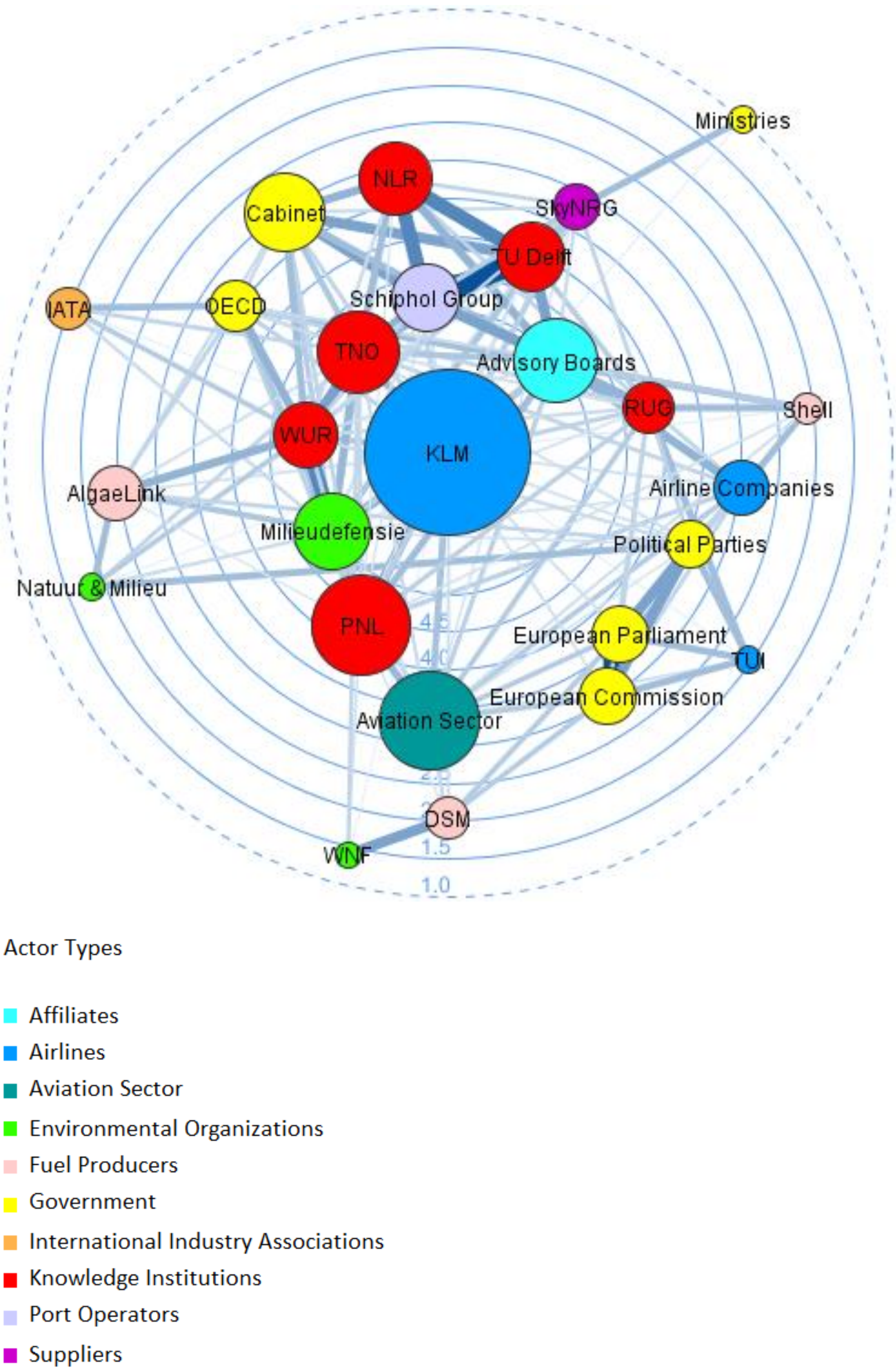


Figure 5: Actor congruence network of Phase I

In the first phase, 26 actors from 10 different actor types engage in the discourse. This period is marked by the emergence of multiple competing logics challenging the long-established supremacy of the regime-maintaining logic, which has been institutionalized in the practices of the socio-technical system for decades. When examining the actor congruence network in *Figure 5*, it is visible that, aside from a few outliers, the network is rather dense. The main actor, KLM, is highly institutionalized in the field, evident from its size and central position within the network. However, KLM's connections with other actors are not particularly strong, especially when compared to the links observed among the three actors NLR, TU Delft and Schiphol Group, for example. The network also indicates that Fuel Producers remain largely on the periphery and are not well-aligned with prominent actors. Similarly, national and international Government appear to be rather detached in the public discourse, although they do have multiple strong connections among themselves as well as with certain Knowledge Institutions. Notably, these Knowledge Institutions exhibit strong alignment with various actors and occupy a central position within the actor congruence network. In this phase of the discourse, three Environmental Organizations are evident, with Natuur & Milieu and WNF taking peripheral positions, while Milieudefensie occupies a more aligned and central spot in the network. The latter aligns particularly well with closely located, institutionalized actors such as WUR, TNO and KLM, indicating congruent statements of these actors regarding certain concepts.

Overall, the discourse during this 2006-2009 period is dominated by Airlines and Knowledge Institutions, as illustrated in *Figure 6*. Together, they account for more than half of the statements made, while most other actor types contribute around 5%. This is in line with the actor congruence network, where KLM and most Knowledge Institutions are relatively large in size and hold central positions in the network, thus in the discourse. Actor type Government includes the same number of actors as Knowledge Institutions but holds a 13% smaller share in statements, with most of the statements originating from Cabinet.

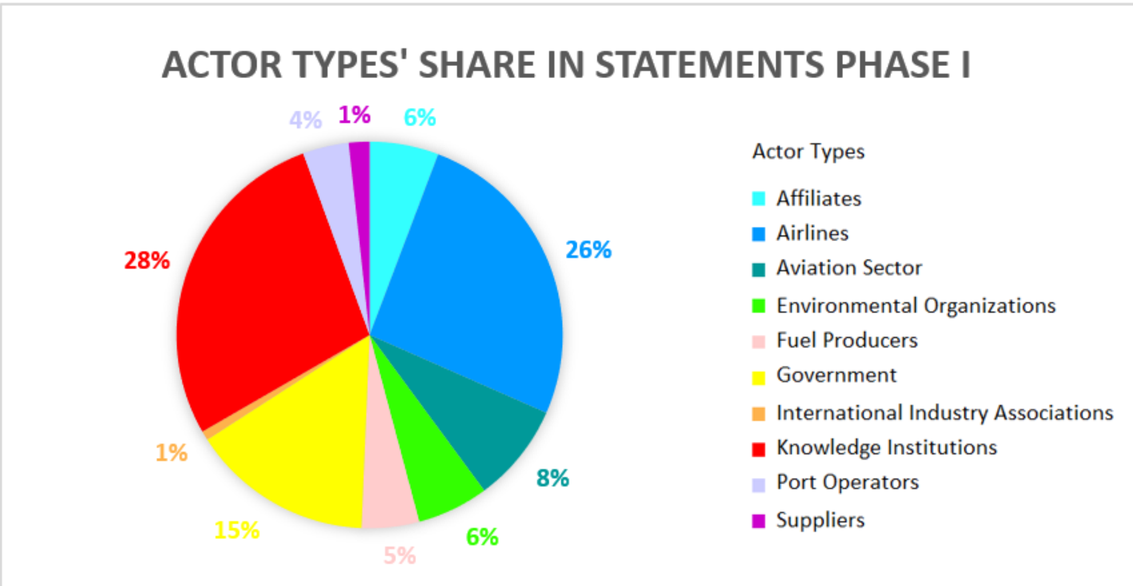


Figure 6: Share in statements of different actor types in Phase I of the discourse expressed in percentages

4.2.1.2 Field logics

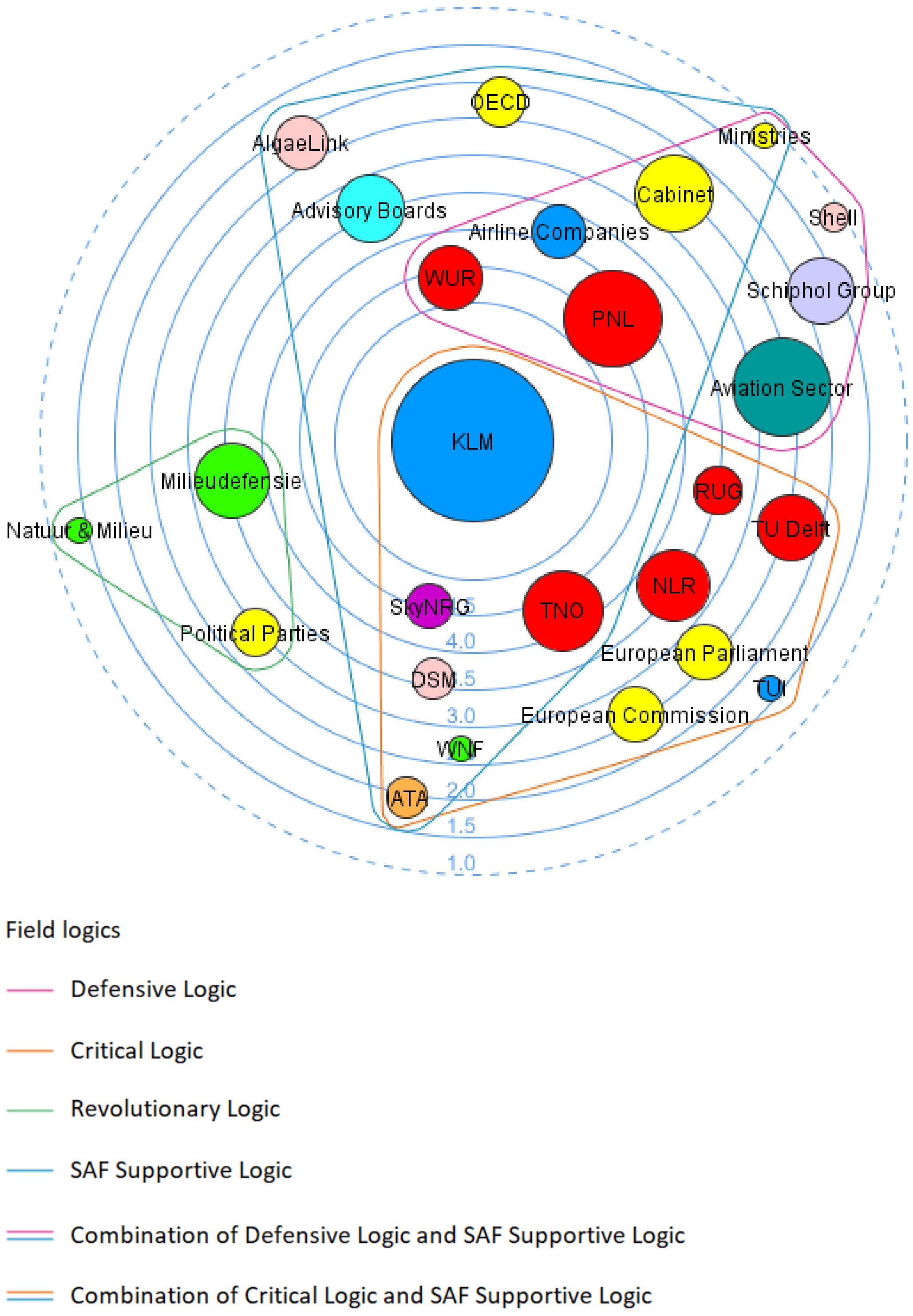


Figure 7: Network displaying the field logics of Phase I

Depicted in *Figure 7* is that in this 2006-2009 period the Defensive Logic is a peripheral logic in the field, with prominent actors such as Aviation Sector and Schiphol Group adhering to it. These actors hold a shared believe that the Sustainable Paradigm will not take over the dominant Conventional Paradigm and argue that fossil-fuel-based kerosene, despite its price increases, will continue to be significant in the future of the industry. Actors such as PNL, Cabinet and WUR partly share this narrative and adhere to the Combination of

Defensive Logic and SAF Supportive Logic. PNL, for instance, articulates its stance asserting the ongoing dominance of the Conventional Paradigm while at the same time revealing support for additional research on SAF. PNL regards the development of biofuel as an ancillary matter and emphasizes that the aviation sector will continue to rely on kerosene for the next decades: “biofuel is currently not a realistic alternative to fossil kerosene. Even with the current soaring oil prices, biokerosene is much more expensive than fossil fuel. This is partly because it is hardly produced anywhere on an industrial scale. Banks and investors are hesitant to invest in the new technology. Biokerosene is still in the financial 'valley of death' that lies between science and commerce. Currently, a litre of kerosene costs around 60 cents, while biofuel costs about 5 euros. Despite this gap, we will closely monitor developments in sustainable aviation fuels.”

There are only a few actors solely adhering to the SAF Supportive Logic. AlgaeLink being one of them, which does not explicitly state their predilection towards either paradigm but do (actively) support the production and development of SAF. Combinations with this logic extend across the network and encompass various actor types. The SAF Supportive Logic not only overlaps with the Defensive Logic, but also forms the Combination of Critical Logic and SAF Supportive Logic. Actors adopting this combination of logics aim for a shift towards a more Sustainable Paradigm by investing in SAF, motivated by their critique of the Conventional Paradigm. The most prominent actor in this logic being KLM, who is among the pioneers advocating the necessity of supporting alternative aviation fuels in anticipation of further rises in oil prices or depletion of oil supplies. Throughout this period, they actively engage in SAF development through various projects, investments and test flights. Moreover, KLM advocates for government arrangements, proposing a blending obligation of 5% to ensure fair competition. The consortium SkyNRG is also part of the Combination of Critical Logic and SAF Supportive Logic, striving to accelerate the use of SAF throughout the entire supply chain, from raw material to aircraft tank. SkyNRG agrees that to truly kick-start the market, a blending obligation is necessary as this has proven effective for road transport. Additionally, the biofuel, which is now shipped from countries such as the US, should in the future come from Europe, preferably the Netherlands. Furthermore, they state that the price of biokerosene needs to decrease significantly, as it is currently three times more expensive than regular kerosene.

There are several actors adhering to solely the Critical Logic, which characterizes as a countervailing trend to the Defensive Logic. The actors within this narrative do not mention any support towards SAF in their statements but do critique the Conventional Paradigm, aiming for a transition towards a more sustainable aviation sector. They believe that this transformation can be achieved, for instance, through more efficient European flights by realizing a single European airspace, commonly referred to as the 'European Single Sky'. Alternatively, they propose developing more aerodynamically efficient aircrafts as well as the implementation of the European Emissions Trading System, where trading in emission rights incentivizes emission reduction and sustainability.

A field logic that resides more on the periphery of the network and does not intersect with other logics is the Revolutionary Logic. Three actors adhere to this logic and assert that the aviation sector must anticipate reduced growth. They emphasize that the sector needs to prepare for this inevitable slowdown, as growth cannot continue indefinitely. Additionally, actors within this logic caution against the aviation industry's 'greenwashing' activities, where airlines attempt to enhance their environmental image through various futile projects. Milieudefensie argues that the number of flights should drastically decrease, with both producers and consumers needing to be more conscientious. They propose achieving this through air travel taxes or excise duties on kerosene to mitigate the aviation industry's escalating emissions.

4.2.1.3 Concept congruence network

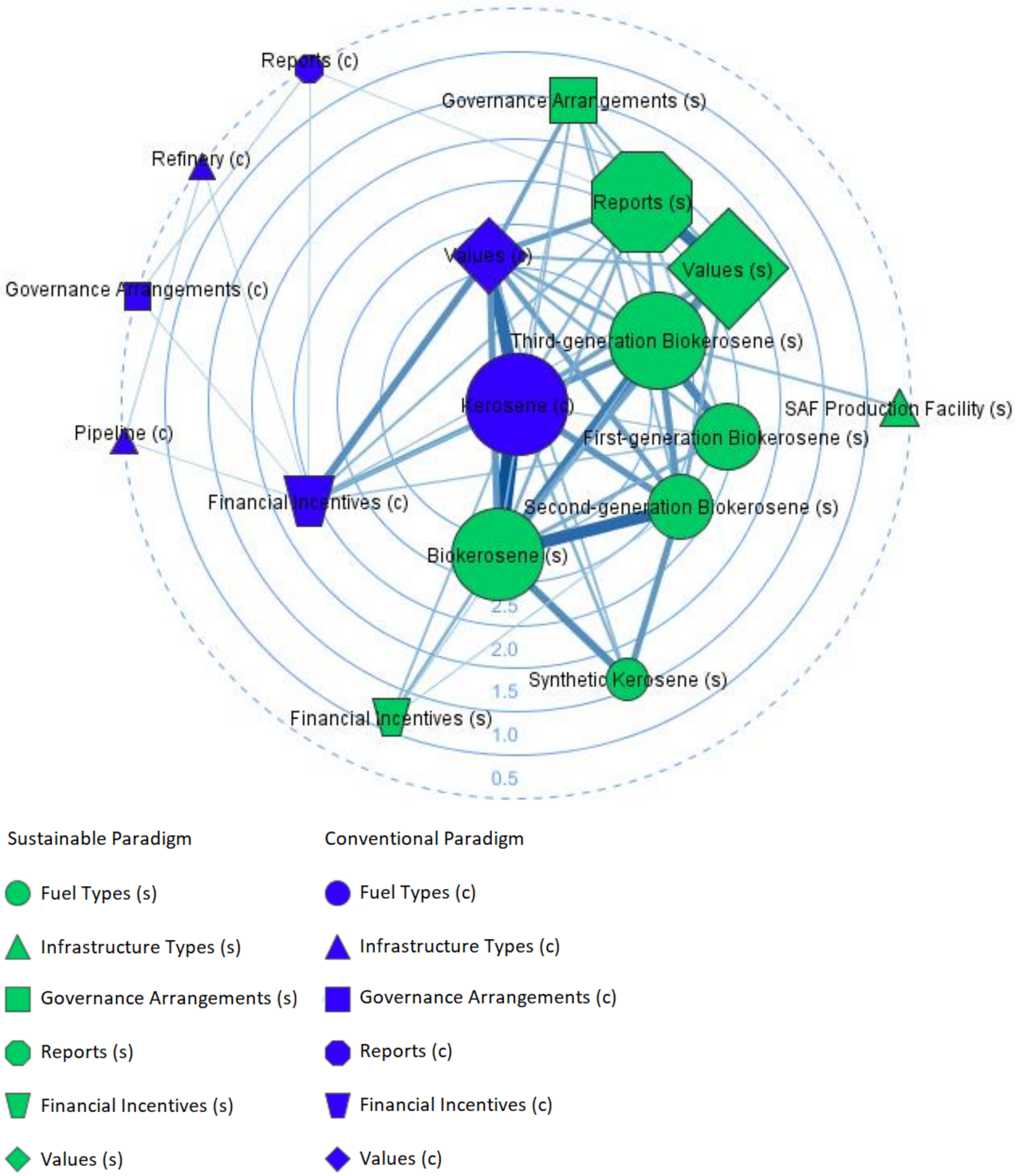


Figure 8: Concept congruence network of Phase I

In Phase I, the fossil-fuel-based Kerosene (c) of the Conventional Paradigm is the most central, institutionalized concept in the network, as visible in *Figure 8*. This Fuel Type is co-mentioned congruently with various other concepts and is referred to by multiple actors, thereby indicating its central role in the public discourse during this time period. It has a particularly strong link with Values (c), as actors congruently co-mention these two concepts, making either supportive or obstructive statements on their fundamental beliefs and principles regarding the Conventional Paradigm as well as on the consumption and production of the Kerosene (c). Actors critical of the Conventional Paradigm frequently make obstructive statements concerning these two concepts, advocating for the withdrawal of subsidies, air travel taxes, CO2 taxes, or excise duties. This coherent storyline is also visible in the well-aligned 'triangle' of Financial Incentives (c), Values (c) and Kerosene (c) in the network, forming a strong configuration in the socio-technical regime. Apart from these three concepts, the other concepts of the Conventional Paradigm are less institutionalized and are therefore situated more on the periphery of the concept congruence network, distant from the deep structure. These concepts mainly demonstrate weak alignments with each other and are not functioning as elements of a socio-technical configuration. Furthermore, they lack substantial connections with the Sustainable Paradigm, which can be attributed to the prevalence of actors in this phase making positive statements on concepts in one paradigm while making negative statements on the other. The potential for mutual benefit between the paradigms in that regard is overlooked, exemplified by the absence of actor's recognition in this 2006-2009 period that a conventional Refinery (c) or Pipeline (c), designed for fossil-fuel-based Kerosene (c), can possibly be repurposed for Biokerosene (s) production and transportation.

The more institutionalized concepts of the socio-technical system do have multiple alignments with concepts from the opposing paradigm. Kerosene (c) for instance, has a strong link with Biokerosene (s), which mainly stems from the desire of multiple actors to gradually replace Kerosene (c) for Biokerosene (s), thereby comprehending that in the near future blending the two is the only reasonable option. One of these actors emphasizes the demand for a drop-in fuel: "Airlines want an alternative to kerosene without anything having to change in the engine. One time the aircraft refuels with biofuel, the next time with kerosene. The blending of any type of biokerosene with conventional kerosene can reach up to 50% and must occur only after certification and strict adherence to safety measures for the biokerosene being used."

Other than Fuel Types, concepts such as Values (s) and Reports (s) are frequently mentioned by numerous actors and moreover have a relatively high degree centrality score, underscored by respectively their relatively large size and central network position. These concepts are fairly deeply institutionalized during this period and exhibit a strong alignment with each other. This connection can be attributed to actors who hold positive values towards the Sustainable Paradigm also referencing or contributing to Reports (s) that underscore the need for SAF in the transition towards sustainability. Reports (s) such as the Knowledge and Innovation Agenda for instance, established by some prominent actors from a variety of actors types, with Knowledge Institutions, Airlines and Port Operators among them. Together, these parties outline, in rather broad strokes, a joint vision for a sustainable and competitive aviation sector. Concerning SAF, this Report (s) mentions that "alternative second or third-generation kerosene is one of the few sustainable options for reducing CO2 emissions. Collaborations are formed within the aviation sector to accelerate research, development and certification of sustainable biofuels. With a strong knowledge base in plant breeding and petrochemistry, the Netherlands could serve as a starting point for a new industry sector with significant potential."

These are rather general visions and expectations regarding the future of aviation biofuel, held by relatively few actors, thereby not providing guidance or direction to learning processes. Despite their lack of robustness or specificity, the content is supported by ongoing projects led by innovative industry partners, such as KLM's test flight with passengers using a blend of Second-generation Biokerosene (s) (with the Camelina plant as feedstock), along with a demonstration flight partially fuelled by algae kerosene in preparation. These local projects not only facilitate increased learning processes but also enhance the legitimacy of the technology. The constituency behind these Fuel Types leads to an accelerated process of social network formation involved in the technological niches of Second-generation Biokerosene (s) and Third-generation Biokerosene (s). While these networks are not yet extensive or deeply rooted, there are interactions among actors from different actor types, mobilizing commitment and willing to provide necessary expertise, people and financial support. This is evident in actions such as KLM and SAF producer

AlgaeLink entering into exclusive contracts, the establishment of consortia such as SkyNRG and the organization of conferences such as 'Sustainable Aviation: Sound and Climate in Perspective' organized by PNL, where multiple types of actors discuss applications of second- and third-generation biofuels. These efforts in social network building are accompanied by increased learning processes on technical aspects, environmental impacts, infrastructure networks and market preferences related to these two technological niches. Actors are gradually learning, for example, which exact feedstocks are most feasible and desirable and explore suitable and efficient locations for production. Moreover, actors are addressing market and user preferences by learning how to reduce (energy) costs and make large-scale production profitable over time, in order to compete with the much cheaper conventional Kerosene (c).

While Second-generation Biokerosene (s) is mainly positively referred to by actors, Third-generation Biokerosene (s) is not an undisputed Fuel Type within the 2006-2009 period of the discourse. Prominent actors in this phase, such as KLM, believe that algae-based biokerosene has the potential to be the cleanest and most sustainable alternative, although it requires time for technological improvements and large-scale cultivation. Other actors in the field, however, dismiss Third-generation Biokerosene (s) as an "algae hype", portraying this Fuel Type as expensive, energy-intensive and technologically complex and emphasize that it faces scaling uncertainties due to low yields. Due to these varying perspectives and voices, Third-generation Biokerosene (s) is one of the main topics in media discourse during this period, preserving a more central position in the concept congruence network. Its strong link with First-generation Biokerosene (s) can be attributed to negative statements from multiple actors who, besides Third-generation Biokerosene (s), also express scepticism about the future of First-generation Biokerosene (s). Reports (s), from TNO for instance, offer critical assessments of First-generation Biokerosene (s), indicating that its utilization is unsustainable as it contributes to deforestation and extreme increases in food prices. These adverse societal and environmental impacts associated with this Fuel Type result in a widespread negative perception towards First-generation Biokerosene (s). The lack of constituency behind its technology leads to a cycle where the social network involved in the technological niche of this SAF remains small, visions are not shared and no pilot projects take place that could potentially lead to more learning processes.

The network illustrates that First-generation Biokerosene (s) is a concept positioned closely to the regime, holding some alignments with technological and institutional concepts, forming a rather weak socio-technical configuration. Furthermore, it is visible that First-generation Biokerosene (s) forms a weak link with the concept Values (s), because almost no actors in this phase hold positive values towards the Sustainable Paradigm while also supporting First-generation Biokerosene (s), underscoring the critiques from the Reports (s). Only Neste experiments with the production of First-generation Biokerosene (s) using palm oil as feedstock, stating that they are aware of the critique but can ensure that their production of this palm oil is 100% traceable and genuinely sustainable. Some actors in Phase I of the discourse, such as SkyNRG, emphasize the importance of utilizing multiple sources for sustainable fuel, mentioning feedstocks for the three generations of Biokerosene (s): rapeseed, waste products from the food industry and algae.

Within the 2006-2009 period of the public discourse, Synthetic Kerosene (s) is referred to by only a few actors. KLM suggests this form of SAF as a potentially cheaper and less harmful alternative for the future. The absence of a technological niche for Synthetic Kerosene (s) in Phase I can be attributed to the fact that actors within the discourse are primarily focused on Biokerosene (s), with limited awareness of Synthetic Kerosene (s). The concept congruence network illustrates this, as the concept holds the lowest degree centrality score of all Fuel Types. Furthermore, Synthetic Kerosene (s) has only several links with other concepts and does not form a socio-technical configuration including technological and institutional elements.

4.2.2 Phase II (2010-2015)

4.2.2.1 Actor congruence network

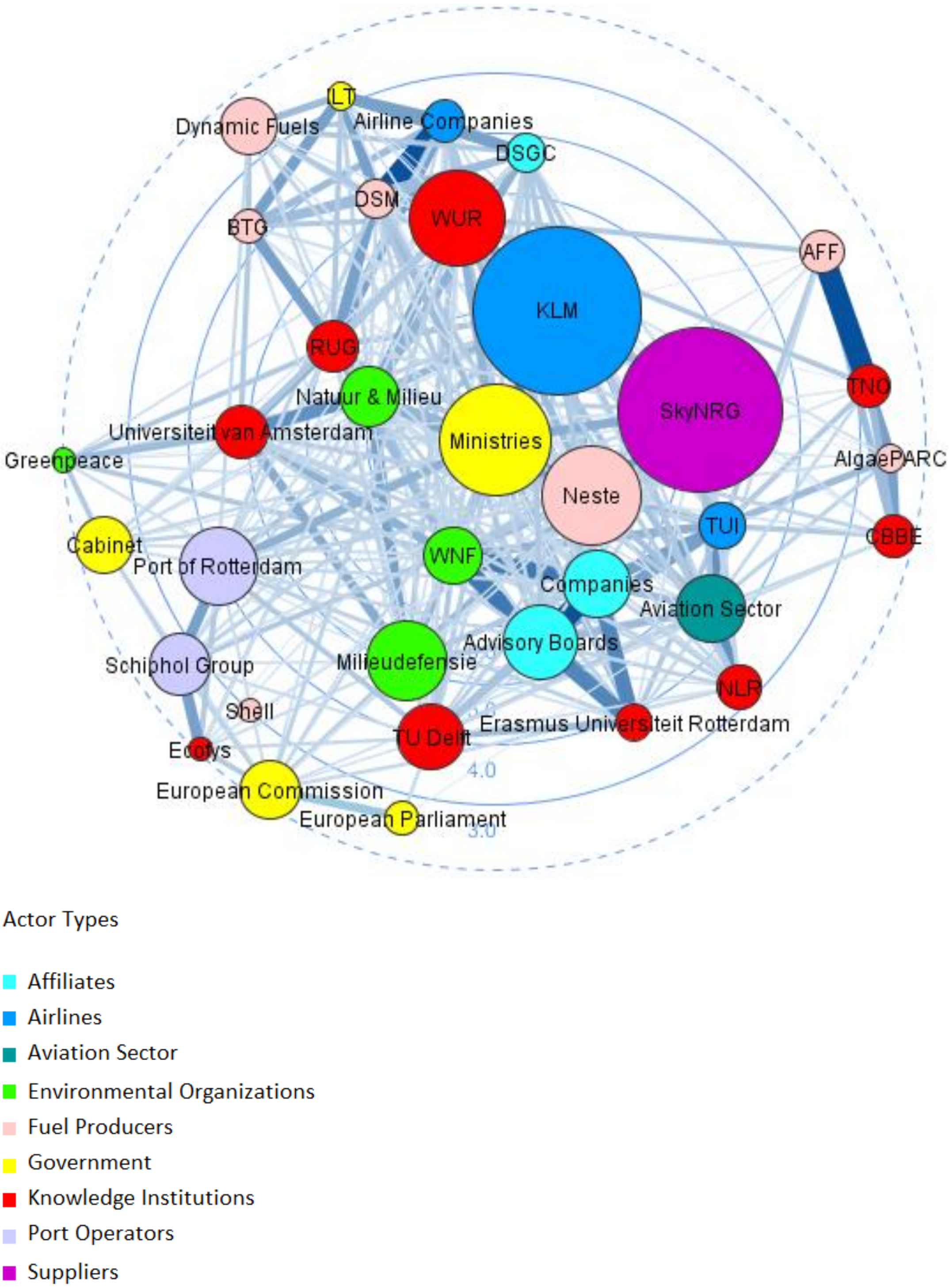


Figure 9: Actor congruence network of Phase II

In Phase II, significantly more actors join the public discourse. This period is characterized by increased intervention of the Dutch government and its more prominent role in shaping the broadened discourse on

SAF. The actor congruence network in *Figure 9* visualizes that KLM remains one of the incumbent actors and Ministries emerging as the most institutionalized actor in the field (refer to Appendix C for a clearer view of the relatively strong links). While Ministries played only a minor role in the first phase, residing on the periphery of the network with only links established with KLM and SkyNRG, it shifted towards being the actor with the highest degree centrality in the network. Additionally, fuel Supplier SkyNRG is also gaining prominence in the field compared to the previous period, forging strong alignments with several established actors.

Another well-established, institutionalized actor in the field with multiple alignments is Fuel Producer Neste, which, in contrast to other Fuel Producers, occupies a central spot in the network. However, these other Fuel Producers display multiple strong connections, notably DSM and AFF with Airline Companies and TNO respectively, indicating congruent statements of those actors on certain concepts. Additionally, strong alignments are visible between Companies and Advisory Boards as well as between their closely situated actors in the network. Besides Ministries, actors from the Government actor type either disappeared from the media discourse or moved further to the network's periphery compared to Phase I, showing relatively few and weak alignments. Apart from the two most vocal Knowledge Institutions, WUR and TU Delft, all Knowledge Institutions have one or more strong connections with nearby actors, residing either around the central actors or further on the network's periphery. Environmental organizations are rather central actors in the field, demonstrating multiple strong links, with the exception of the new, weakly institutionalized actor in de broadened discourse, being Greenpeace. Furthermore, the actor congruence network illustrates Schiphol Group's shifts to a more peripheral role compared to the 2006-2009 period, forming strong connections with two new actors in this phase: Ecofys and the Port of Rotterdam.

Overall, the discourse in phase II is more dispersed than in the first phase, with half of the actor types contributing for more than 10% in statements, as illustrated in *Figure 10*. Airlines remains the most dominant actor type, making the most media statements, where Suppliers increases 15% in share compared to the previous period. The substantial amount of statements of these two actor types are largely attributed to KLM and SkyNRG respectively, as evident from their size in the actor congruence network. Knowledge Institutions are making almost the same amount of statements as in the first phase, yet significantly drop in percentage due to the increased total amount of statements in the second phase of the discourse.

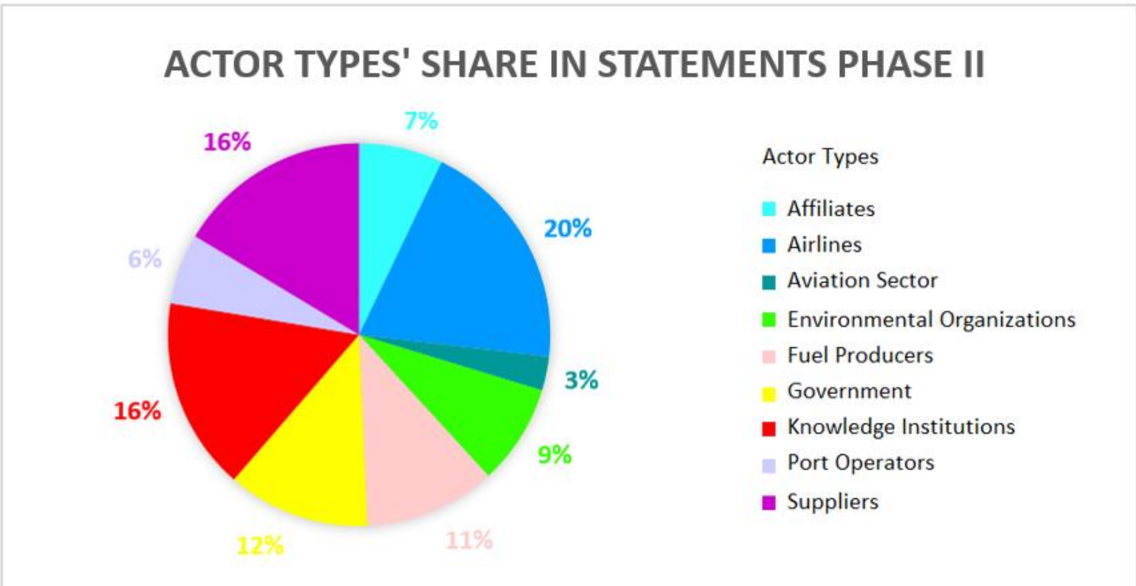


Figure 10: Share in statements of different actor types in Phase II of the discourse expressed in percentages

4.2.2.2 Field logics

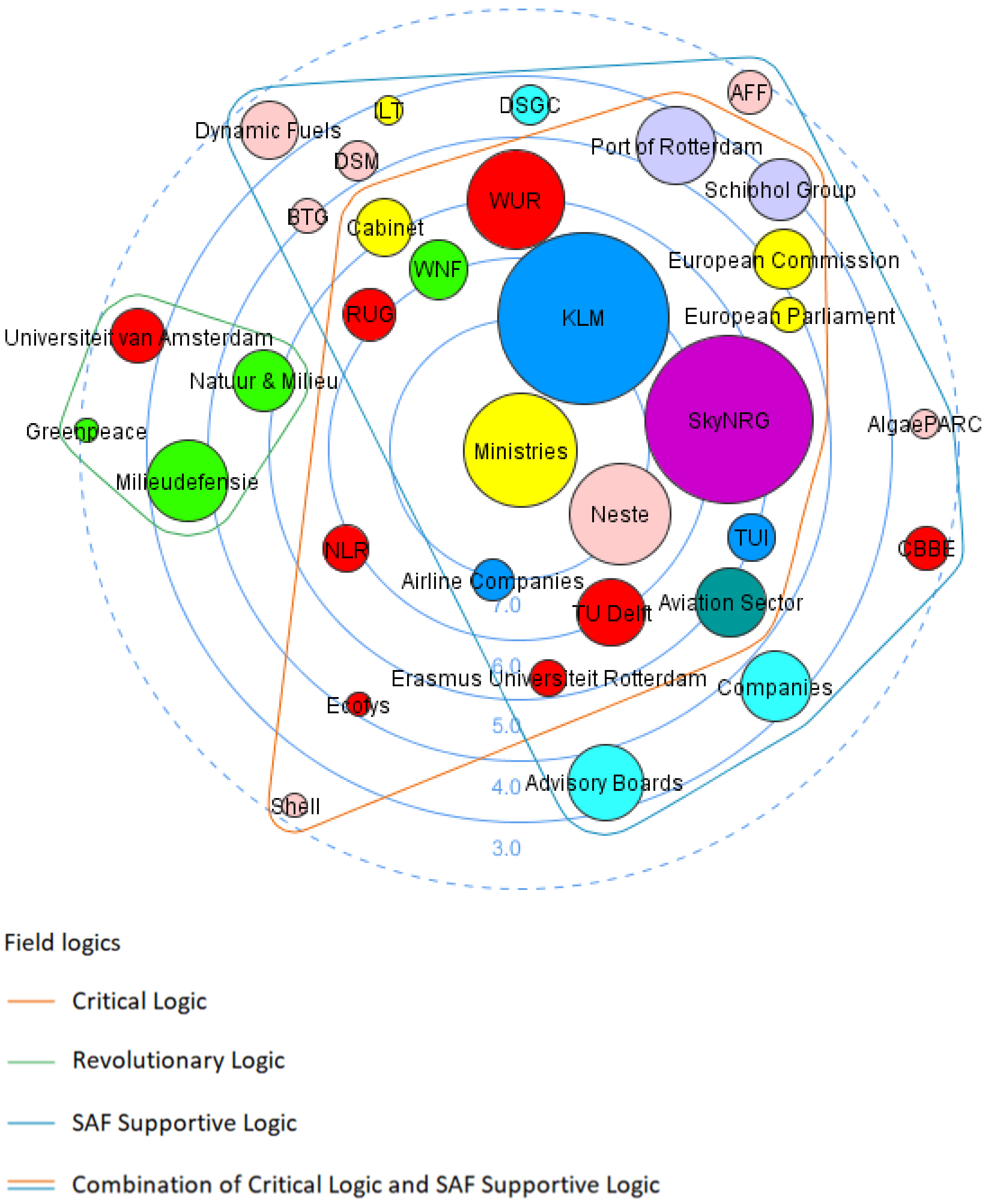


Figure 11: Network displaying the field logics of Phase II

It is visible in the network of *Figure 11* that in this 2010-2015 period the Defensive Logic is no longer present in the discourse. While it once prevailed as an undisputed, institutionalized logic before the introduction of SAF and was still followed by some prominent actors in Phase I, this field logic is now expelled, since there are no actors remaining who adhere to this conservative advocacy coalition. The statements made by actors during this period of the discourse show that they are adopting the sustainability trend and no longer reveal a predilection towards the Conventional Paradigm. For instance, Schiphol Group, initially hesitant in the first phase viewing fossil-fuel-based kerosene as the most reasonable aviation fuel to use for the short and medium term, made a transition towards a different narrative. In this phase they follow a more critical narrative and even commit to a declaration of intent aimed at widespread adoption of sustainable biokerosene. Sixteen other actors in Phase I also adhere to this Combination of Critical Logic and SAF Supportive Logic. As visible in the field logics network, this logic dominates the discourse and has shifted further towards the centre compared to the 2006-2009 period. The most prominent actor in this field logic is Ministries, who was supporting SAF in the first phase while adhering to the Combination of Defensive Logic and SAF Supportive Logic, is now increasingly critical towards the Conventional Paradigm. This shift is exemplified by the Council of Ministers approving a proposal to promote the use of SAF in the aviation sector, under the condition that this fuel is sustainably produced and does not compromise, for instance, nature reserves. Additionally, the substance must perform significantly better in terms of CO2 emissions than fossil fuels. The European Commission, who shifted from the Critical Logic to this Combination of Critical Logic and SAF Supportive Logic, underscores this as well. On one hand, they aim for a sustainable aviation transition by enforcing stricter regulations within the Emissions Trading System, exploring measures such as implementing a carbon or VAT tax, or imposing excise duties on kerosene. Simultaneously, they initiate a program to bolster the production, storage and distribution of SAF within European countries.

Other prevalent actors within this field logic, committed to fostering a transition towards a Sustainable Paradigm through the promotion and investment in SAF, include KLM, Neste and SkyNRG. However, KLM and SkyNRG offer a nuanced perspective compared to other actors within this logic, asserting that existing policies overly emphasize levies and emissions trading. They argue that widespread adoption of SAF can only occur if prices decrease and if entrepreneurs and governments provide sponsorship. Furthermore, they advocate, as they did in Phase I, for the introduction of a blending obligation to incentivize ‘fossil players’ and jump-start the market. Four Knowledge Institutions within this logic emphasize the unsustainability of aviation. While TU Delft acknowledges progress within the sector, they state that “technical improvements involving lighter materials and more streamlined are necessary. The biggest gains can be made in terms of fuel efficiency. Replacing kerosene with a biological alternative would make a significant difference. The government should subsidize this more expensive fuel, or impose taxes on fossil fuel to make it competitive for airlines. However, the realization of such measures ultimately depends on political will.”

Aside from Neste and Shell, Fuel Producers present in this 2010-2015 period of the discourse all adhere to the SAF Supportive Logic. Their statements indicate active support and contribution to the production and development of SAFs, without expressing a critical or defensive stance towards any paradigm. It remains unclear whether they are producing sustainable fuels with the intention of making the aviation sector more sustainable or simply capitalising on the trend for personal financial gain and to uphold a positive, green image to the public.

A few actors in Phase II adhere to the Critical Logic, including Shell, NLR and Ecofys. NLR holds the belief that biofuels are not a significant solution as traditional fuel will continue to dominate for decades: “it is relatively cheap and has the highest energy yield per kilogram, which is why it is so popular”. However, NLR maintains a critical stance towards the Conventional Paradigm and aims to contribute to a more sustainable aviation industry by participating in initiatives such as the Clean Sky Program, which is a joint undertaking that develops quieter and more environmentally friendly aircrafts through, for instance, sustainable and green engines and eco-design.

A field logic that is still on the periphery of the field and not interfering with other logics is the Revolutionary Logic. The actors adhering to this logic have a shared believe that the current approach of actors from opposing field logics does not effectively mitigate the greenhouse effect. According to Natuur & Milieu, optimism regarding biofuels is entirely misplaced. Activists, primarily from Greenpeace, are expressing strong criticism of the use of palm oil for fuel production. They also reject other forms of SAF, stating that “in the midst of the climate crisis, we cannot rely solely on innovation. Ceasing growth is the only option for the aviation sector to combat climate change." Milieudefensie emphasizes that the absence of taxes on kerosene and the exemption of tickets from VAT, the Cabinet is essentially subsidizing a polluting activity. To steer the aviation sector toward sustainability, revolutionary change is imperative, they argue. Accordingly, both polluting companies and consumers should pay significantly more and the number of flights must be drastically reduced.

4.2.2.3 Concept congruence network

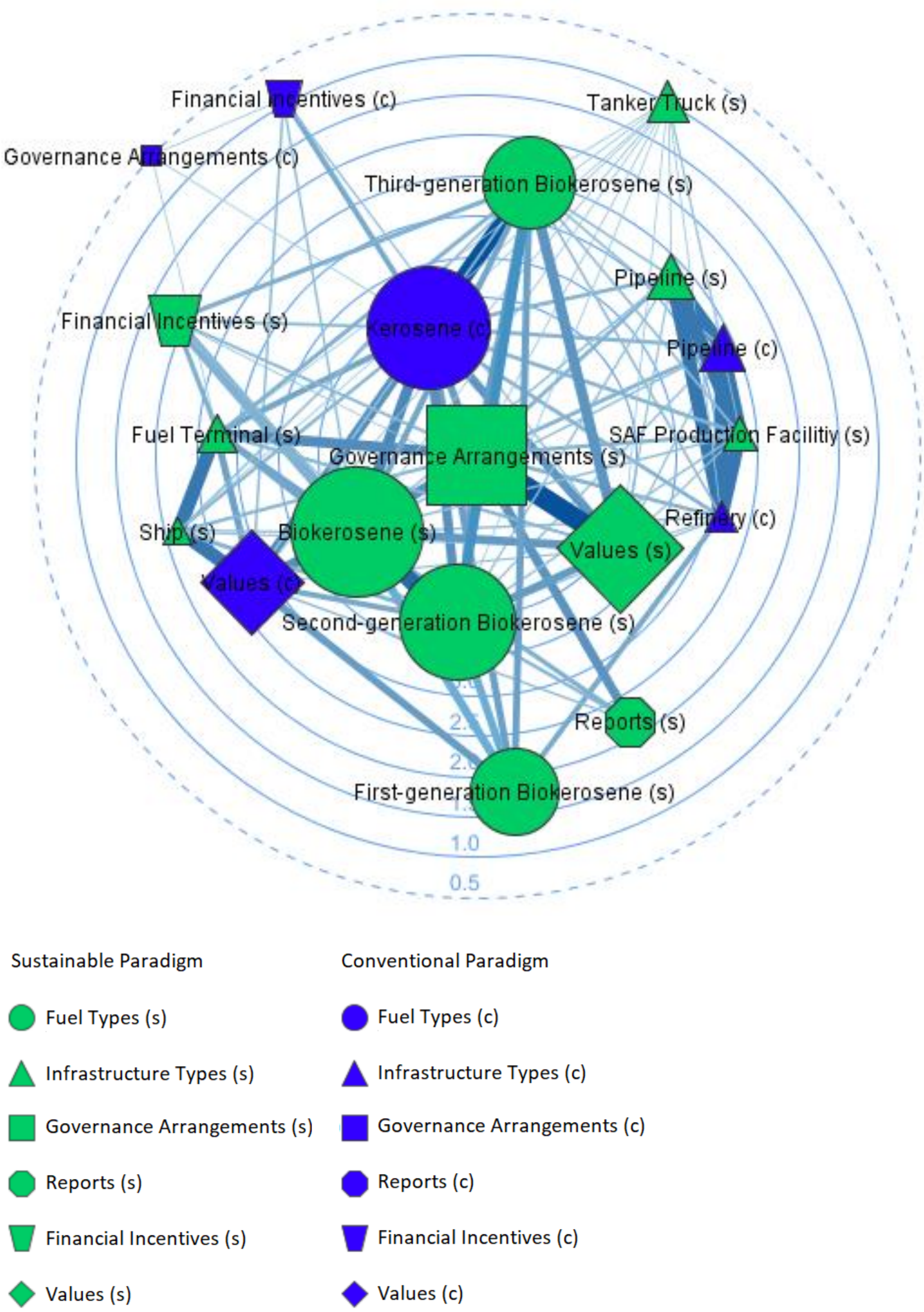


Figure 12: Concept congruence network of Phase II

In the 2010-2015 period, Kerosene (c) is no longer the concept with the highest degree centrality score in the network and is replaced by Governance Arrangements (s) from the Sustainable Paradigm, as visible in *Figure 12*. This concept is co-mentioned congruently with multiple other concepts by actors in Phase II of the discourse, making it the most central and key concept in the socio-technical regime. Governance Arrangements (s) displays multiple strong links with concepts of its own paradigm and forms a particularly strong link with Values (s). This is largely due to actors who hold a positive stance towards the Sustainable Paradigm and simultaneously make supportive statements on certain Governance Arrangements (s), such as new legislation, regulations and policy objectives aimed at effectively achieving a more sustainable aviation sector. For example, several actors from different actor types expressed positivity regarding new legislation, which categorizes Biokerosene (s) under the umbrella of biofuels. This renders Biokerosene (s) more attractive for Fuel Producers particularly, who are mandated by regulations introduced in this phase to ensure that 4.5 percent of the marketed fuel is of renewable origin.

The network visualizes that, contrary to Phase I, concepts from the Conventional Paradigm are no longer grouped together but are more dispersed across the entire network, aligning with concepts from both the Sustainable Paradigm and the Conventional Paradigm. This is particularly evident in the Infrastructure Types concepts of both paradigms, which were not connected in the first phase but are now strongly linked, indicating a coherent storyline. This storyline emerges in this 2010-2015 period from actors stating that biofuel can “simply” be transported through the underground pipes (s) at Schiphol, whereas it previously had to be delivered separately by Tanker Truck (s). Additionally, a Refinery (c) that was once used for producing Kerosene (c), diesel, or other fossil fuels can now be used to produce Biokerosene (s) and other biofuels. This utilization of existing infrastructure bridges the Sustainable Paradigm and Conventional Paradigm, allowing their concepts to form connections with each other.

Furthermore, the concept congruence network shows that Kerosene (c) and Biokerosene (s) are both central actors forming strong alignments. Their mutual link remains due to actors who state that, in the short term, blending Kerosene (c) with Biokerosene (s) is the initial step towards the pursued replacement of fossil-fuel-based fuel with biofuel. The socio-technical configuration between Kerosene (c), Values (c) and Financial Incentives (c), which was clearly visible in the first phase, is still present in this period but has weakened. This is indicated by their weaker mutual links and increased distance from each other. Consequently, the storyline detected in the first phase persists but is less prominent in Phase II of the media discourse.

The concept Reports (s) shifted from being a rather institutionalized and aligned concept in the first period to a concept at the periphery of the network in Phase II. The Reports (s) during this 2010-2015 period mainly focus on the cultivation of the Jatropha plant, a feedstock for First-generation Biokerosene (s), highlighting issues such as the exploitation of farmers, deforestation and the negative impact on local food production. Additionally, top-down intervention is taking place, as both Ministries and the European Parliament are voting for legislation to phase out First-generation Kerosene (s) in the near future and implement stricter sustainability measures for SAF. For this reason, actors from both Airlines and Fuel Producers refrain from using and producing First-generation Biokerosene (s), if they had not done so in the first phase. This joint negative stance and increasing vocal criticism of this Fuel Type results in the technological niche of First-generation Biokerosene (s) ceasing to exist in Phase II. It no longer forms a social network of actors willing to commit resources and support its development. In the concept congruence network it is visible that First-generation Biokerosene (s) does make several connections with other concepts, but fails to form a socio-technical configuration.

A Fuel Type that is also subject to criticism is Third-generation Biokerosene (s), nonetheless forming a configuration close to the deep structure. It exhibits a rather strong link with Values (s), driven by actors who are making positive statements on the Sustainable Paradigm as well as on Third-generation Biokerosene (s). However, the network does not demonstrate the frequent criticism levelled against this type of SAF for its lack of economic viability and its slow progress in technological advancements related to oil extraction from algae. While there are ongoing learning processes within this technological niche, evident from halving of production costs for Third-generation Biokerosene (s) over recent years, these advancements are not yet substantial enough to significantly propel the development of this niche. The price-performance issue is also demonstrated by the research funded by Ministries, conducted by AlgaePARC, which subsequently developed a roadmap and program for the development and demonstration of large-scale biokerosene production from algae, at competitive costs. This vision for further algae development is shared by airline TUI, with which WUR collaborates, but is not followed by a lot of other actors. For example, KLM says it is still working on Third-generation Biokerosene, but it has “taken a backseat” since they have shifted their focus on other SAF alternatives.

TNO argues in this 2010-2015 period of the discourse that oils from algae could be better utilized for other purposes such as the food or cosmetic industries, where potentially a factor of 100 more money could be obtained compared to Biokerosene (s). Such obstructive statements stem from actors who also express negative sentiments about fossil-fuel-based Kerosene (c), hence the strong link and close association between Third-generation Biokerosene (s) and Kerosene (c). Compared to Phase I, there is not much more constituency behind the technology of Third-generation Biokerosene (s), as the social network involved in this technological niche established in the first period has not been expanded further. Moreover, the KLM-linked SkyNRG considers algae-based fuel as an alternative but is not actively engaging other actors in this niche.

In this phase, actors show a stronger preference for Second-generation Biokerosene (s). The concept congruence network depicts that this concept has a rather high degree centrality score and is referred to by a considerable amount of actors, indicated by its central position and size, respectively. Furthermore, the network illustrates that it is well-aligned with closely situated concepts, particularly from the Sustainable Paradigm. Processes of development within the technological niche of Second-generation Biokerosene (s), which commenced in Phase I, are now advancing across multiple fronts in this phase. Two incumbent actors, KLM and Ministries, are forming concrete sustainable agreements and initiatives by jointly compiling the Biofuel Action Plan, which primarily focuses on Second-generation Biokerosene (s). Although these expectations lack specific quantitative targets, KLM pledges to facilitate knowledge exchange with actors across the supply chain, the NGO sector, corporate accounts, government and academia. Additionally, Ministries is providing a subsidy of over 1 million euros to KLM, as a Financial Incentive (s) to accelerate the development of Second-generation Biokerosene (s) that uses Camelina plants as feedstock. Actors who express positive sentiments towards both concepts in their statements contribute to the alignment observed in the network between Second-generation Biokerosene (s) and Financial Incentives (s).

Second-generation Biokerosene (s) is also aligning with the most central concept in the network Governance Arrangements (s), formed by actors making supportive references to arrangements related to this Fuel Type. Statements on the efforts of prominent actor SkyNRG for instance, who manages to obtain an official certification of their supplied Second-generation Biokerosene (s), allowing it to be blended with conventional Kerosene (c) for commercial flights, eliminating safety concerns. Consequently, to promote Second-generation Biokerosene (s) and drive down costs by increasing demand, SkyNRG and KLM launch their Corporate Biofuel Program, where companies pay a premium to fly on a Camelina plant blend. This initiative not only fosters additional learning processes but also contributes to expanding the social network and legitimize this Fuel Type. SkyNRG acknowledges, however, that the feedstocks for Second-generation Biokerosene (s), remain three to four times too expensive and are also depleting in the short term. Multiple actors in the discourse suggest to focus on a mix of used cooking oil, Camelina plants and algae. This underscores the relatively strong connection between Second-generation Biokerosene (s) and Third-generation Biokerosene (s) within the network.

Since Phase I, actors, including KLM and SkyNRG, have been establishing a robust supply chain for the production, transport, storage and use of Second-generation Biokerosene (s). KLM is now operating commercial flights using a blend of kerosene derived from used cooking oil and conventional Kerosene (c). That is, Second-generation Biokerosene (s) is integrating with existing practices in the regime, which no longer exists of solely fossil-fuel-based Kerosene (c). This niche is breaking through and successfully reconfiguring the established socio-technical regime into a new one during this 2010-2015 period. The network visualizes this, with both conventional Kerosene (c) and Second-generation Biokerosene (s) being part of the core configuration.

To scale up Second-generation Biokerosene (s), SkyNRG partners with KLM, Schiphol, Neste, the Port of Rotterdam and two government Ministries in the BioPort Holland consortium. Their joint aim is to collaboratively develop strategies for producing and transporting used cooking oil, constructing a supply chain in the Netherlands specifically dedicated to this Second-generation Biokerosene (s). In this second phase of the discourse, Synthetic Kerosene (s) is not mentioned by any actor, neither positively nor negatively. As a result, this concept is absent from the network and there is still no technological niche existing for this Fuel Type.

4.2.3 Phase III (2016-2023)

4.2.3.1 Actor congruence network

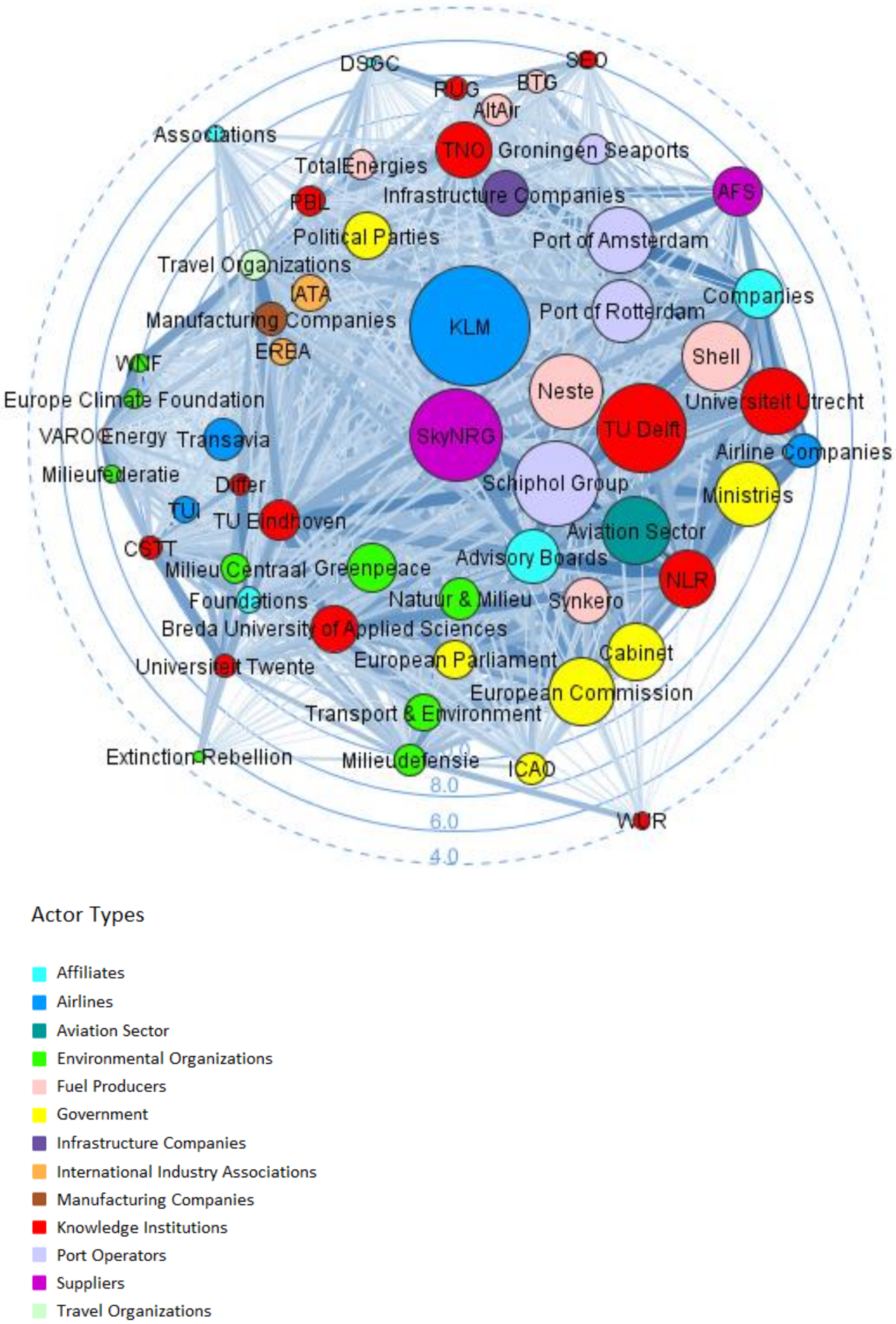


Figure 13: Actor congruence network of Phase III

In Phase III, the discourse involves 56 actors across 13 different actor types. This period is characterized by collaboration among various actors to develop and implement plans for establishing a SAF supply chain and building SAF Production Facilities (s) to scale up production and meet demand. *Figure 13* visualizes that the actor congruence network in this 2016-2023 period is dense and highly interconnected, with more alignments between actors compared to previous phases (refer to Appendix D for a clearer view of the relatively strong links). Notably, SkyNRG emerges as the most central actor in this period of discourse, exhibiting strong connections with closely located actors and weaker connections with more peripheral actors in the field. SkyNRG's trajectory mirrors that of Ministries in the previous phase, transitioning from a peripheral actor to an incumbent actor in the field, obtaining the highest degree centrality score.

KLM, a shareholder of SkyNRG since its inception, remains a highly institutionalized actor in the field, indicated by both its size and central position in the network. It establishes strong connections with actors from various types, notably with Port Operator Schiphol Group, which is also a prominent actor in this phase of the discourse. Furthermore, the network depicts that most actors positioned close to the centre are well-aligned with each other. Knowledge Institutions such as TU Delft, Universiteit Utrecht, NLR and TU Eindhoven, for example, participate in multiple coherent storylines with various actors in the field. However, WUR has shifted from being one of the most institutionalized Knowledge Institutions in the previous phase to a rather detached actor in the public discourse, indicated by its location on the periphery of the network and its relatively few and weak connections.

Ministries remains a well-aligned actor but has transitioned from being the most prominent, central actor in Phase II, to an actor positioned away from the regime, on a similar distance as the other Government actors. Although being mostly weakly institutionalized actors in the field, the amount of actors from Environmental Organizations present in the discourse has more than doubled since the last phase. Among them, Milieu Centraal, Greenpeace and Natuur & Milieu emerging as particularly well-aligned actors. Fuel Producer Neste remains one of the most institutionalized actors in this 2016-2023 period, with two other Fuel Producers, Synkero and Shell, also making congruent statements with the more prominent actors within the organizational field.

Overall, the public discourse of the 2016-2023 period is consisting of more actor types and exhibits a similar level of dispersion as in the previous phase, as depicted in *Figure 14*. One-fifth of all statements made in Phase III originate from Knowledge Institutions, the actor type that has been partly dominating the discourse since the first phase. Their increase in share in statements can largely be attributed to the participation of 13 different Knowledge Institutions, each contributing their perspectives on the current state and future prospects of SAF. Airlines, Port Operators, Government and Fuel Producers each contribute 12 or 13% to the discourse. Airlines significantly declines in their percentage since the first phase, primarily due to KLM being the sole prominent participant in the discourse from this actor type. Port Operators, on the other hand, have steadily increased their presence in the media discourse over the periods, with particularly Schiphol Group, Port of Rotterdam and Port of Amsterdam making statements regarding SAF production, distribution and storage. SkyNRG and AFS, the only Suppliers active in this phase, decline in their share in statements compared to the last period due to the increased total amount of statements made by other actors.

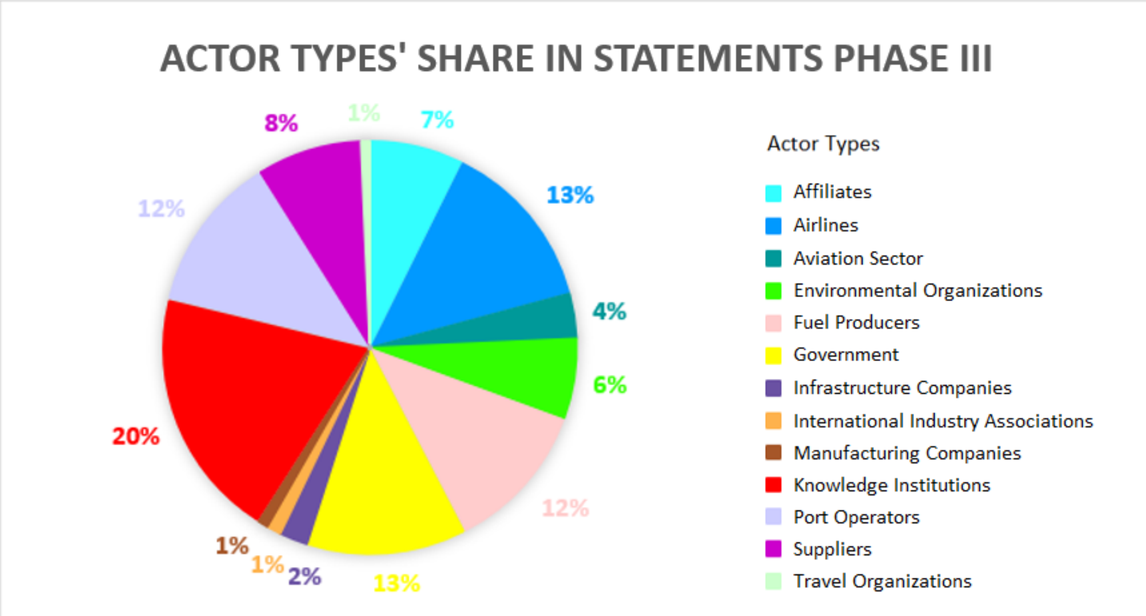
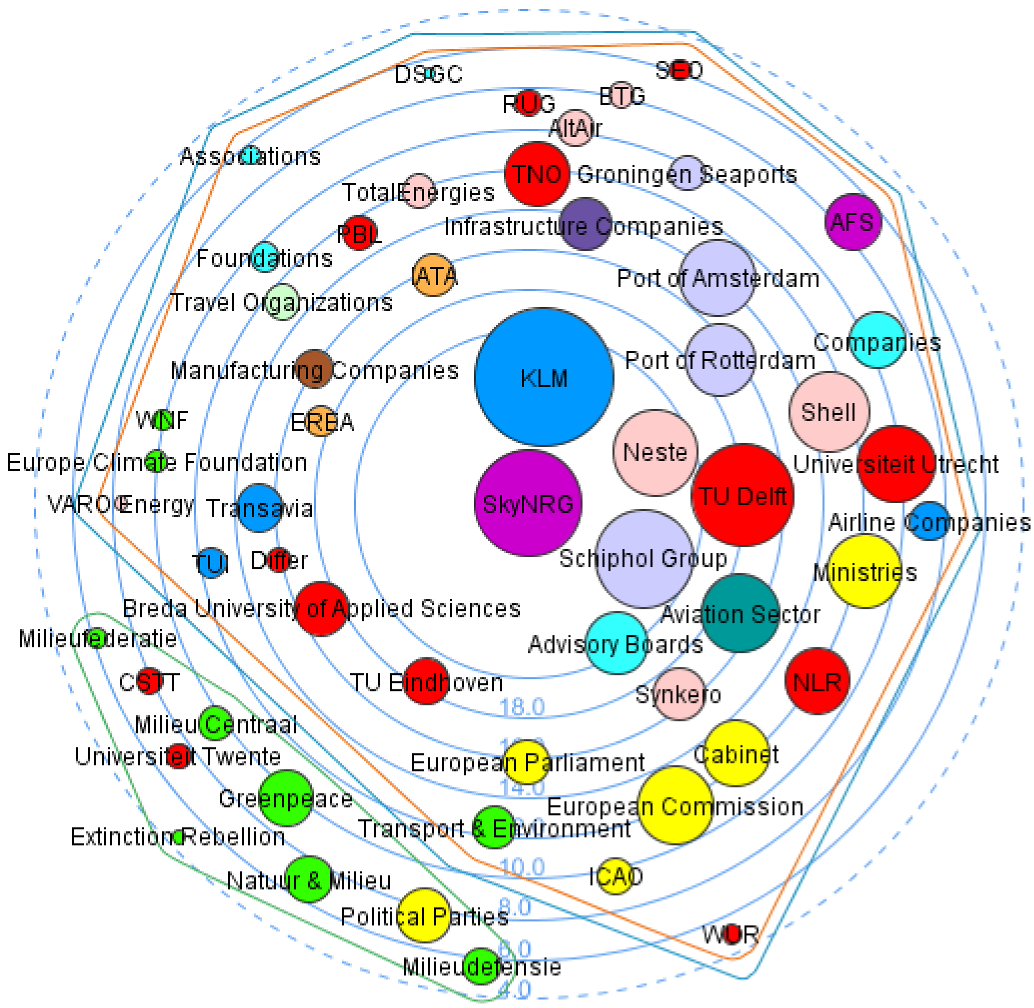


Figure 14: Share in statements of different actor types in Phase III of the discourse expressed in percentages

4.2.3.2 Field logics



Field logics

SAF Supportive Logic

Combination of Critical Logic and SAF Supportive Logic

Figure 15: Network displaying the field logics of Phase III

It is illustrated in *Figure 15* that in Phase III only two field logics remain present in the discourse: the Combination of Critical Logic and SAF Supportive Logic and the Revolutionary Logic. The Critical Logic as well as the SAF Supportive Logic on their own, which were adhered to in the first two phases, now disappeared as all of its actors shifted to the combination of these two logics. The network shows that this dominant logic stretches over the whole network and is followed to by nearly all actors. The actors adhering to this Combination of Critical Logic and SAF Supportive Logic share the belief that a transition towards a Sustainable Paradigm can be achieved by investing in the development and diffusion of SAF.

Even NLR, which clearly stated in previous phases that biokerosene is not worth investing in for achieving a more sustainable aviation sector, now adheres to the Combination of Critical Logic and SAF Supportive Logic. NLR emphasizes that achieving a zero-emissions sector may take several decades due to scarcity of resources, lack of efficiency and the high demand for biofuel in sectors beyond aviation. They assert that "innovation is crucial because the technical challenges are significant. However, in the coming years, we will still have to rely on the existing fleet, which we can make more sustainable through the use of alternative sustainable fuels and more fuel-efficient engines." The more incumbent actors of this period also acknowledge that the availability of raw materials is a bottleneck. SkyNRG emphasizes that the Cabinet will therefore need to make a substantial effort to increase capacity, raising the political question of how to distribute resources among various industries. Both SkyNRG and KLM adhere to this Combination of Critical Logic and SAF Supportive Logic since Phase I and reiterate in this third phase that large-scale utilization of SAF is the most effective way to reduce CO2 emissions in the aviation industry. "Keep in mind that there is no silver bullet", TU Delft cautions. The Knowledge Institution calls for government policies that focuses on more a fuel-efficient and cleaner aircraft, as well as on sustainable kerosene and a robust Emissions Trading System. The Aviation Sector is also among the numerous actors emphasizing the urgent need for government subsidies. They propose that the Cabinet should allocate the money that can be raised from an aviation tax to scale up the production of SAF. This initiative requires the collaboration of Fuel Producers, who, as visible in the network, are now all adhering to the Combination of Critical Logic and SAF Supportive Logic. They are willing to actively participate in the transition from a Conventional Paradigm to a Sustainable Paradigm by dedicating a portion of their production to SAF. Including Shell, which stated in Phase I that they believed the aviation sector could not be made sustainable.

The only actor part of the Government actor type that does not adhere to this logic is Political Parties. This actor was absent in the 2010-2015 period of the discourse, but now stands as one of the prominent actors that adhere to the Revolutionary Logic, the narrative they followed in Phase I as well. Their contention remains that the aviation sector is excessively exempted, advocating for sustainability through a raise in the established VAT tax as well as for excise duties on conventional kerosene, preferably implemented at the European level, to discourage the established Conventional Paradigm.

The University of Twente also advocates for degrowth of the industry, stating that "aircrafts will never become quieter and cleaner faster than aviation grows. So there needs to be a brake on that growth, that is the only solution". This Revolutionary Logic primarily involves actors from Environmental Organizations, with Milieu Centraal, Extinction Rebellion and Milieufederatie being new participants in this phase of the public discourse. All actors adhering to this field logic share the narrative that a revolutionary change in the aviation sector's "mindset" is imperative, urging for the reduction and discouragement of air travel rather than investing in "superficial solutions" such as SAF. Natuur & Milieu and Milieu Centraal assert that producing environmentally friendly fuel demands an enormous amount of sustainable energy, energy that is also needed for the energy transition. Greenpeace contends that the technological developments of SAF are progressing too slowly and calls for more consumer awareness, expanded high-speed train networks and fairer ticket pricing. As illustrated in the network, the Revolutionary Logic remains a peripheral logic that, despite gaining more adherents, is not succeeding in coming close to the institutionalized centre of the field.

4.2.3.3 Concept congruence network

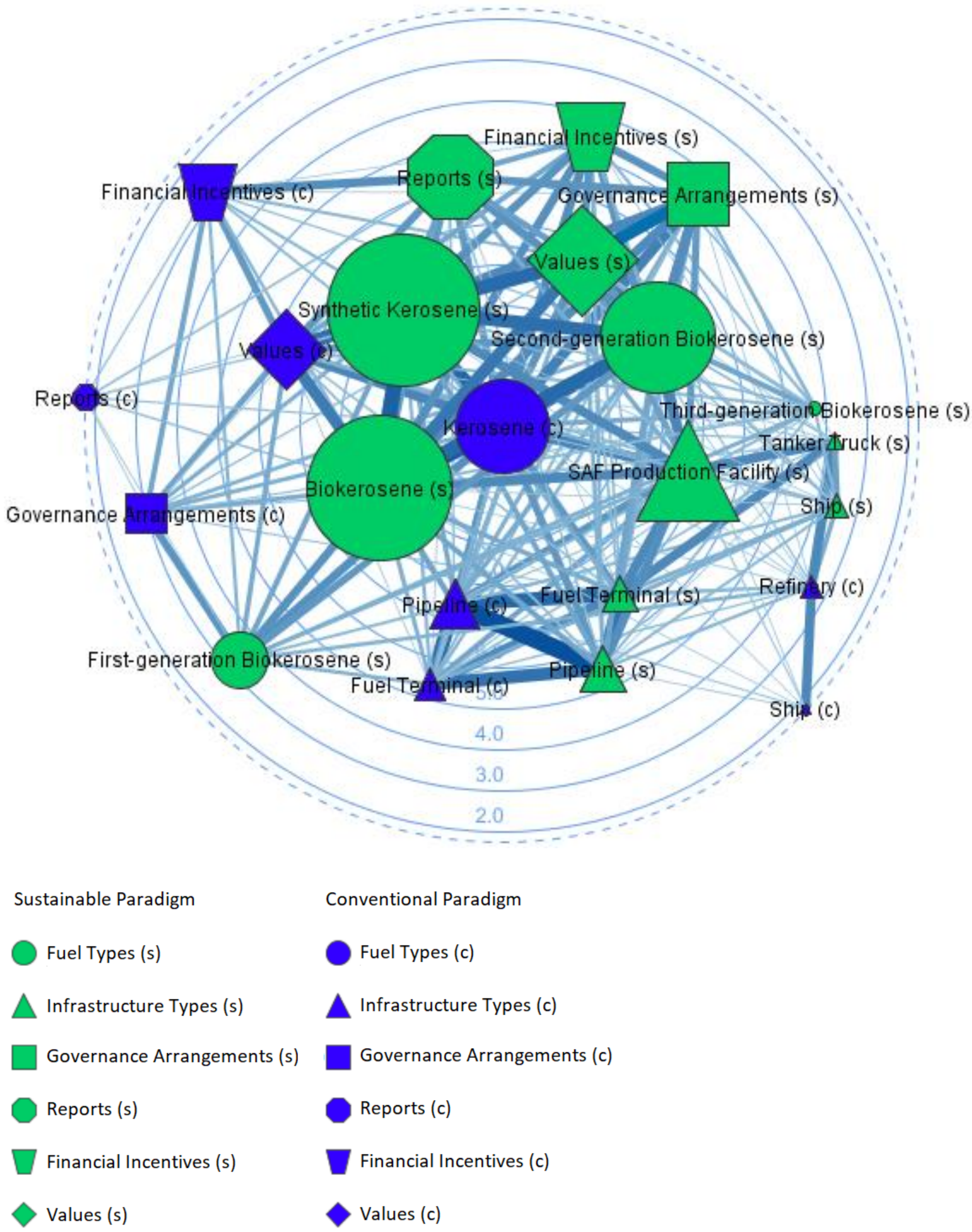


Figure 16: Concept congruence network of Phase III

Figure 16 demonstrates that in the 2016-2023 period, Kerosene (c) is the concept with the highest degree centrality in the network, as it was in the first phase. This Fuel Type occupies a central spot in the socio-technical regime of Phase III, as it is congruently co-mentioned with numerous concepts from both paradigms. Kerosene (c) displays multiple strong alignments with concepts from the Sustainable Paradigm, particularly with Fuel Types. These connections arise from actors acknowledging that, in the short term, flying on a blend of Kerosene (c) and SAF is the sole option to gradually shift towards a sustainable aviation sector free of fossil fuels. This coherent storyline is reflected in the network by the socio-technical configuration among Values (s), Kerosene (c), Biokerosene (s) and Synthetic Kerosene (s). The strong alignments between these prominent Fuel Types also result from actors making obstructive statements about them, driven by their aversion to conventional Kerosene (c) and their belief that SAF is progressing too slowly to significantly impact the aviation industry's transition towards sustainability in the near future. This storyline is visible in the network through the alignments among Values (c), Kerosene (c), Biokerosene (s) and Synthetic Kerosene (s).

The concept congruence network reveals that concepts from the Conventional Paradigm are less scattered across the network than in Phase II, but are not forming a strong socio-technical configuration with each other. Apart from Kerosene (c), concepts from the Conventional Paradigm are peripherally located and are not well-institutionalized. There are notable strong alignments, especially among concepts from Infrastructure Types (c), which align well with Infrastructure Types (s) concepts from the Sustainable Paradigm. As in Phase II, this storyline is shaped by actors supportively co-mentioning these concepts, emphasizing that the Pipelines (c) and Fuel Terminals (c) used for transporting and storing fossil-fuel-based Kerosene (c) can also be utilized for SAFs without requiring much additional effort or investment.

The concept Governance Arrangements (s), which was the most central and institutionalized concept in the last phase, remains well-aligned but is now situated more on the periphery of the network, away from the deep structure. It maintains a strong alignment with Values (s), formed by actors making congruent positive statements on these concepts. For instance, these actors make supportive statements on the blending mandate of SAF established by the European Commission and endorsed by the Cabinet to encourage industry investments in the production and use of SAF in the pursuit of a Sustainable Paradigm. In earlier phases, various actors had strongly advocated for this mandate. Now, in Phase III, the European Commission has set a future obligation to blend 6% SAF, with 0.7% needing to be Synthetic Kerosene (s). Governance Arrangements (s) also holds alignments with closely located concepts Financial Incentives (s) and Reports (s). In this 2016-2023 period, multiple Reports (s), among others stemming from TU Delft and TNO, indicate that producing renewable Synthetic Kerosene (s) in the Netherlands is economically and technically feasible in the relatively short term. Synthetic Kerosene (s) is relatively energy-dense, allowing large quantities to be easily stored in tanks. Additionally, one Report (s) suggests that Synthetic Kerosene (s) has the potential to make the entire Dutch aviation sector CO_2-neutral by 2050. However, its current production process is energy-intensive and costly, necessitating government policies to reduce the price gap with conventional Kerosene (c). To provide guidance, the Report (s) outlines various scenarios for the energy demand for Synthetic Kerosene (s) in 2030 and 2050. Financial Incentives (s) in this phase include funding from the Nationaal Groeifonds, with the Cabinet investing €383 million to facilitate the aviation transition, particularly through three projects focused on developing knowledge, infrastructure and an ecosystem for Synthetic Kerosene (s). This funding request was submitted by TU Delft, along with Ministries, NLR, Schiphol Group and SkyNRG.

These supportive Reports (s) and subsequent Financial Incentives (s) are fostering strong constituency behind this Fuel Type, encouraging more actors to mobilize necessary resources and provide financial support. Moreover, actors from various actor types are articulating their views and committing to development through their respective smaller networks. Numerous actors in this period sign the Sustainable Aviation Agreement, thereby sharing the vision that Synthetic Kerosene (s) will be a promising SAF to invest in for the medium term. Additionally, KLM conducts the first test flight on a blend of Synthetic Kerosene (s), in collaboration with various actors including Shell and government Ministries. Furthermore, two pilot plants for the production of Synthetic Kerosene (s) are now operational, with one in the Port of Rotterdam and another in the Port of Amsterdam.

Backing visions with these projects leads to increased legitimacy, as well as increased learning processes on for instance technical aspects and infrastructure networks. New knowledge circulates through the expanding social network of actors, prompting further articulation of strategies and expectations, thereby facilitating the formation of new collaborations. The partnership between prevalent actors SkyNRG, Synkero, KLM, Schiphol Group and Port of Amsterdam for example, who formulate plans for the construction of a SAF Production Facility (s) in the Port of Amsterdam dedicated to the production of Synthetic Kerosene (s). That actors congruently co-mention Synthetic Kerosene (s) and SAF Production Facility (s) in their statement is visible in the concept congruence network, indicated by the rather strong alignment between these two concepts.

Synthetic Kerosene (s), which received minimal attention in the discourse during previous phases, has now become the most institutionalized form of SAF in the network. Synthetic Kerosene (s) is well-aligned with various concepts from both paradigms and is the most frequently referenced concept by actors in this period of the discourse. Additionally, the networks illustrates that the concept is now part of the central socio-technical configuration, which Kerosene (s) and Second-generation Biokerosene (s) are also part of. Although Synthetic Kerosene (s) is not utilized in commercial flights yet, it is integrating with existing practices in the socio-technical regime and moreover set to be mandated for blending in the near future. In this third phase, the technological niche of Synthetic Kerosene (s) is developing rapidly and is even successful in reconfiguring the socio-technical regime, which now encompasses Kerosene (c) as well as two types of SAF.

However, some actors caution that there is a limited supply of sustainably generated hydrogen, which serves as the feedstock for Synthetic Kerosene (s). Additionally, they note in this 2016-2023 period of public discourse that production is costly due to the complex production process. NLR states: “to make synthetic fuel competitive with regular kerosene, the green hydrogen economy must first become operational, which can only happen when a lot more green electricity is available”. Nonetheless, most actors advocating for a sustainable transition of the Dutch aviation industry see potential in this form of SAF as long as production scale increases, illustrated by the strong link between Synthetic Kerosene (s) and Values (s) in the concept congruence network. Synthetic Kerosene (s) also exhibits a strong alignment with Second-generation Biokerosene (s), which can be attributed to the fact that multiple actors make positive statements on both of these fuel types.

Multiple actors, including KLM, assert that used cooking oil can serve as a bridging fuel until Synthetic Kerosene (s) is used on widespread commercial scale. Additionally, they recognize that utilizing this feedstock for the production of Second-generation Biokerosene (s) is finite and therefore has less potential for long-term scalability compared to Synthetic Kerosene (s). To enable ambitions during this bridging period, production of Second-generation Biokerosene (s) within the Netherlands, rather than importing by Ship (s), is imperative. A consortium consisting of SkyNRG, Shell, KLM, Schiphol Group and an Infrastructure Company is collaborating with Groningen Seaports to construct a SAF Production Facility (s) in Delfzijl, which will produce biokerosene from used cooking oil and other organic waste fats.

Furthermore, both Shell and Neste are constructing a factory in the Port of Rotterdam, where plant residues as well as used cooking oil will serve as feedstock for producing Second-generation Biokerosene (s). This mobilization of necessary physical and knowledge infrastructure, along with the articulated joint visions by individual actors or consortia, underscores the legitimacy of Second-generation Biokerosene (s) within the socio-technical regime of this third phase. Learning processes from projects involving the Camelina plant have led to KLM now using this feedstock to blend with Kerosene (c) for commercial flights as well. The network displays that this Fuel Type is forming even stronger alignments with concepts of the core socio-technical configuration it is part of than in Phase II.

First-generation Biokerosene (s) is, as it was in the previous phase, a peripheral Fuel Type. The concept is no longer forming a socio-technical configuration, although it has some concepts it aligns with. First-generation Biokerosene (s) exhibits a rather strong link with Values (c), stemming from actors making obstructive statements on First-generation Biokerosene (s) while holding a negative stance towards the Conventional Paradigm. As in the previous two periods, this Fuel Type is referred to mostly negatively in the media discourse, particularly by Environmental Organizations, who strongly oppose the use of materials such as palm oil and soy oil. Additionally, Neste announces that they will gradually phase out the use of palm oil for Biokerosene (s) production, which they had long defended as being "truly sustainably produced". The technological niche of First-generation Biokerosene (s) ceased to exist in Phase II and remains absent in this third phase as well, indicated in the network by the concept not forming a socio-technical configuration. Similarly, the technological niche of Third-generation Biokerosene (s) is not present in this 2016-2023 period, also evident from the disappearance of its socio-technical configuration. Third-generation Biokerosene (s) is mentioned only a few times in this phase of the discourse and has shifted to being a poorly aligned and peripheral concept. SkyNRG notes that the warnings about an "algae hype" in earlier phases have proven to be justified: "the use of algae for kerosene has virtually disappeared. Most companies that were active during the algae boom have since gone bankrupt." Large-scale production as well as achieving significant cost reduction in Third-generation Biokerosene (s) production continued to be a challenge throughout the three phases. The remaining algae companies have shifted their focus to higher-value products such as nutrients or substances for the cosmetics industry.

5. Conclusion

The aim of this thesis was to explore how and under what circumstances technological niches of SAF can reconfigure the interlinked social and technical elements of a socio-technical regime in the context of the Dutch socio-technical system of aviation fuel. This was achieved by performing a Socio-Technical Configuration Analysis in which actor congruence networks and concept congruence networks visualize the structure of the socio-technical system and the change in socio-technical regime over time. In addition to these networks, STCA offered the ability to analyse the underlying relational dataset to gain more context regarding both the identified technological niches and their configurational shifts, as well as the identified actors and their field logics. This research aimed at answering the following research question:

How and under what conditions can technological niches of SAF reconfigure the regime of the Dutch socio-technical system of aviation fuel?

This thesis distinguished four technological niches of four different SAFs: first-generation biokerosene, second-generation biokerosene, third-generation biokerosene and synthetic kerosene. The analysis revealed that the technological niches of first-generation biokerosene and third-generation biokerosene ceased to exist in Phase II and Phase III respectively, therefore failing to break through and integrate with the socio-technical regime.

The technological niche of first-generation biokerosene was only present in the first phase and faced significant criticism. The actors experimenting with or promoting first-generation biokerosene were unable to mobilize other actors and build constituency around the technology. This failure was primarily due to critical reports and environmental organizations framing this type of biokerosene as unsustainable, environmentally harmful and food-competitive. Other institutional efforts to discourage first-generation biokerosene included lobbying for strict regulations for first-generation biokerosene, primarily driven by actors within the Revolutionary Logic. Despite being part of this peripheral field logic, these actors successfully conveyed their message to other actors in the field. This led to powerful, institutionalized actors from other field logics such as KLM, Schiphol Group and certain knowledge institutions, also contributing to the dismantling of the socio-technical configuration of first-generation biokerosene. The data analysis unveiled that particularly the agency of these more powerful actors of the 2006-2009 period contributed to the inability of this technological niche to develop.

Moreover, in the second phase, the technological niche of first-generation biokerosene disappeared entirely due to top-down interventions, with both the Dutch government and the European Parliament voting for legislation to phase out first-generation kerosene. The analysis revealed that as policymakers become more institutionalized and wield greater power within the field, as observed in Phase II, they can leverage their institutional power to implement policy measures that hinder the further development of a technological niche or even 'push it into the valley of death'.

In the first two phases, third-generation biokerosene was perceived by numerous actors as the sustainable long-term solution for aviation. Powerful actors during these periods, such as KLM, WUR and Ministries, initially included this type of SAF as part of their strategy, establishing a social network that involved actors willing to invest in research and legitimize algae fuel. However, the analysis showed that these expectations and visions were not translated into test flights or large-scale projects. As a result, actors were unable to learn from user experience or from potential failed experimental projects, leading to a lack of guidance in the social network.

Due to only a few actors committing to this third-generation biokerosene and policymakers remaining hesitant to allocate further investments or infrastructure, the social network involved in this niche gradually diminished. Limited learning processes resulted in production costs not significantly decreasing and technical advances of the technology progressing too slowly. Consequently, ongoing price-performance issues and significant uncertainties in scaling up persisted. These problems were magnified by actors adhering to the Revolutionary Logic, who attempted to undermine institutional support for third-generation biokerosene by dismissing this SAF as an "algae hype" and an "unrealistic alternative". The data analysis furthermore revealed that influential actors such as KLM and SkyNRG were affected by this applied institutional work, redirecting their focus toward SAFs with greater scalability options.

In contrast to the other two generations of biokerosene, the technological niche of second-generation biokerosene successfully reconfigured the socio-technical configuration of the regime. During the first two phases, this technological niche experienced rapid development, forming stable and robust social networks of resourceful actors who circulated knowledge regarding for instance infrastructure and market preferences. This collaborative effort led to the narrowing down of numerous potential feedstocks to the Camelina plant and used cooking oil. Strategies and visions were shared and supported through test flights and actor collaborations, creating a cycle of heightened expectations and increased learning processes on technical and environmental aspects within and between projects.

In addition to these learning processes reducing the costs of second-generation biokerosene over the years, the niche of this SAF capitalised on the soaring oil prices for fossil-fuel-based kerosene caused by the energy crisis. This profit from "ongoing dynamics" led to heightened expectations among various actors to further close the price gap between these fuels, accompanied by increased resource and actor mobilization. Another critical moment in the sector's historical development was the shift in political ideology in the Netherlands, which resulted in increased government intervention and the establishment of relational power structures between key actors KLM and Ministries in Phase II. The analysis showed that this power structure led to government subsidies being allocated to KLM to enhance research and development, resulting in increased learning processes and stronger constituency behind second-generation biokerosene.

These two incumbent actors also formed concrete sustainable agreements and initiatives regarding second-generation biokerosene by jointly compiling a Biofuel Action Plan. At the same time, both established actors and newly joined actors of the prevailing Combination of Critical Logic and SAF Supportive Logic contributed to further legitimizing this type of SAF through institutional support. The agency of these actors effectively countered the institutional work from actors belonging to other institutional environments, such as the Revolutionary Logic, who were persuading public authorities and modifying public perception in their pursuit to de-institutionalize second-generation biokerosene.

Furthermore, institutional efforts from intermediary actors such as SkyNRG led to the official certification of their supplied second-generation biokerosene, allowing for its safe blending with conventional kerosene in commercial flights, thereby eliminating institutional barriers. The data analysis demonstrated that this alignment with dynamics in the existing regime, in the form of hybridization of conventional technology with new technology, also played a significant role in the integration of the niche with the established regime. This hybridization could be facilitated by the absence of 'sunk investments' in existing technology and the drop-in nature of this SAF, which could seamlessly integrate with existing infrastructure and aircraft engines without requiring significant additional investments.

The technological niche of synthetic kerosene was not yet present in Phase I and Phase II, but underwent rapid development, ultimately successfully reconfiguring the socio-technical regime in Phase III. The analysis revealed that this technological niche was able to capitalise on previous learning processes and network building in other niches. In particular, the developments within the technological niches of second- and third-generation biokerosene in the first two periods served as a 'springboard' for the niche of synthetic kerosene. The leveraging of learning processes on supply, infrastructure, storage, blending, safety and user practices, as well as benefiting from the established heuristics and agreements within consortia, partnerships and other social networks notably aided in the rapid development of the technological niche of synthetic kerosene.

The data analysis demonstrated that the favourable niche-regime dynamics observed for second-generation biokerosene, due to its hybrid compatibility with existing infrastructure, also partially facilitated the integration of the niche of synthetic kerosene into the socio-technical regime. Additionally, power relations between policymakers and incumbent actors such as SkyNRG, Schiphol Airport and KLM encouraged broader and more specific visions and strategies as well as significant investments in large-scale projects. Efforts were focused on constructing production facilities and the necessary infrastructure for synthetic kerosene, alongside the development of knowledge infrastructure to combat the production challenges associated with this SAF.

Furthermore, expansions of the social network of resourceful actors involved in this niche facilitated a test flight using a blend of synthetic kerosene and the operation of two test plants. This fostered additional learning processes and built constituency behind synthetic kerosene. Additionally, institutional efforts from actors within the expanding Combination of Critical Logic and SAF Supportive Logic led to future mandatory blending of synthetic kerosene, resulting in further legitimization of this SAF and articulation of actor expectations. The analysis also unveiled that criticism and de-institutionalizing agency from actors adhering to the Revolutionary Logic could readily be marginalized, because the Combination of Critical Logic and SAF Supportive Logic was prevailing in Phase III, wielding significant power in the organizational field.

6. Discussion

6.1 Limitations

This research faced several limitations that have to be considered in the context of its reliability. The first limitation concerns the selection of relevant articles, which was based on a search string designed to encompass a comprehensive representation of the discourse on the Dutch socio-technical system of aviation fuel. Crafting this search string relied on the use of relevant keywords, which were subjectively determined, making the process susceptible to researcher bias. In particular because this search string was built iteratively, meaning new keywords were added based on the evaluation of sampled articles. This makes it challenging for an external verifier (such as a supervisor) to assess whether the search string and thereby the sampled articles are truly relevant and comprehensive. This researcher bias undermines the internal validity of the study to a certain extent.

To verify the influence of search string design on data sampling and outcomes, research replication by another researcher could be conducted. This approach would help determine to what extent a different search string would affect the data sampling process and the study's final results. A second limitation of this research is the public discourse bias. This research filtered in Nexis Uni on 'Dutch National Newspapers', which only represents the strategies and opinions presented in the media, which are often carefully curated. Although desk research was performed to gather additional attributes for actors, projects and collaborations, data collection could have been improved by conducting interviews with (experienced) actors in the field. These interviews would provide a more in-depth understanding of the aviation sector, allowing for the comparison of actor's media statements with more candid one-on-one conversations. These interviews could furthermore offer insights into internal communication and inter-organizational communication or even serve as a means to validate the findings of the STCA, enhancing the research's depth and validity.

A third limitation of this study pertains to the coding scheme, which depends on researchers' subjective interpretation, introducing potential bias. Although the coding scheme was examined and discussed with the supervisor to mitigate some researcher bias, internal validity could have been better ensured by allowing a second coder applying the coding scheme through multiple coding runs, involving feedback rounds as well as inter-coder reliability checks.

Further limitations are revolving around the created visual networks. Due to the presence of various types of SAF, there are more concepts associated with the Sustainable Paradigm than with the Conventional Paradigm. The resulting abundance of green concepts may give the impression that the Sustainable Paradigm dominates the network, although this may not necessarily be the case. Another limitation within the concept congruence networks is the incorporation of the concept 'Biokerosene (s)', which is based on statements from actors referring to biokerosene in general rather than mentioning specifically first-, second-, or third-generation biokerosene. While the inclusion of 'Biokerosene (s)' in the concept congruence networks proved useful for the analysis, the presence of this concept may complicate the interpretation of these networks. A last limitation of the networks concerns the inability to depict the field logics within the actor congruence networks. It would have been valuable to observe which specific actors, through their bridging alignments, acts as mediators and connecters of different field logics. However, due to differences in the coding methodology of the actor congruence network and the field logics in this study, it was only possible to create two separate networks.

6.2 Theoretical implications

This research employed STCA as a methodological tool to gain insights into how an under what circumstances technological niches can break through and reconfigure the established socio-technical regime into a new one. It is the first time STCA has been applied in this manner and it proved to be an effective approach, as both the visual networks and the qualitative nature of the data allowed for analysing emerging socio-technical configurations (technological niches) and the established configuration (regime), as well as the impact of institutionalized actors and shifts in field logics on the socio-technical system. The analysis revealed that, apart from the internal niche processes and necessary windows of opportunity suggested by SNM scholars within existing literature, other additional conditions contribute to the successful breakthrough of a technological niche:

- The alignment of a technological niche with the dynamics of the existing regime, through the hybridization of conventional and new technologies, can result in the successful reconfiguration of the regime by forming a hybridized structure.
- Relational power structures between incumbent firms and policymakers exert such significant influence on the socio-technical system that when their institutional support is directed towards a specific technological niche, it enhances the possibilities for this niche to integrate into the system's regime.
- The learning processes that have been accumulated within a stabilized technological niche can be leveraged to a newly emerging technological niche if the social networks involved in these niches include partly the same operating actors. The learning processes in one niche can then serve as a springboard for the development and thereby the possible breakthrough of another niche.

6.3 Future research

This study discerned three developmental phases based on three identified critical moments: the energy crisis resulting in the indication by IATA of soaring oil prices to extreme heights in 2006, a shift in political ideology in 2010 and the ratification of the Paris Agreement in 2016. Another critical moment expected to impact discourse activity and the momentum of socio-technical reconfigurations is the COVID-19 crisis, which lasted approximately until 2022. This crisis might serve as a 'reset for aviation', potentially influencing the socio-technical regime to such an extent that the development of SAFs accelerates even further or new windows of opportunity arise for new types of SAF. This critical moment was not incorporated into this study because the research was conducted too soon after the Covid-19 crisis ended to accurately assess how the discourse had changed as a result.

Future research could therefore focus on this 'Phase IV' in the discourse, examining shifts in configurations, actor alignments and field logics. This could potentially provide additional insights to complement the findings of this study or address other transition-related questions within the context of the Dutch socio-technical system of aviation fuel.

7. Acknowledgements

I would like to express my special thanks to Dr. Gaston Heimeriks for his supervision on this master's thesis. His guidance helped me steering in the right direction while allowing me the freedom to think independently. I would also like to thank Johan Miörner and Jonas Heiberg for providing the R scripts that were necessary for successfully applying the STCA method.

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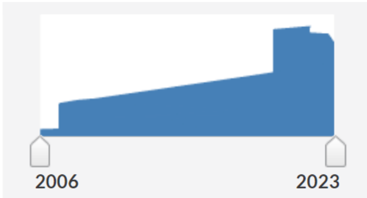
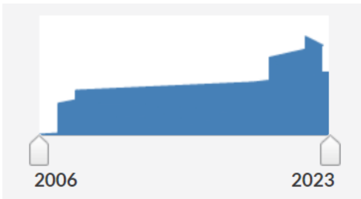
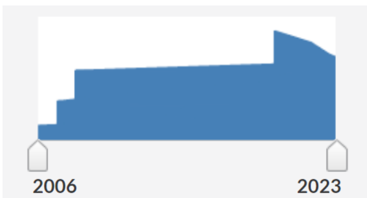
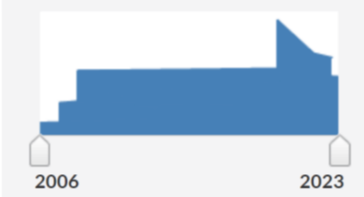
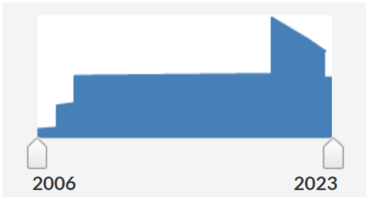
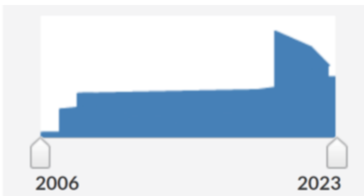
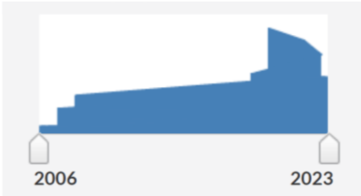
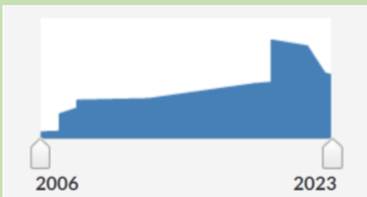
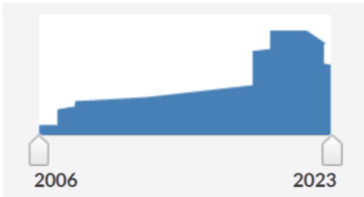
9. Appendices

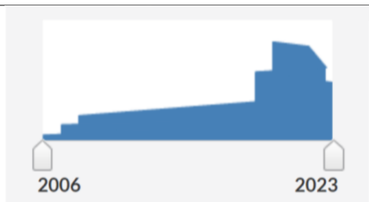
9.1 Appendix A: Sequence of trials of search strings to obtain a representative sample of articles

Trial	Search string	Results	Time trend	Evaluation
1	biokerosine or biobrandstof* or (synthetisch* w/s kerosine) or (synthetisch* w/s brandstof*) or (duurza* w/s kerosine) or (duurza* w/s brandstof*) or (SAF w/s duurza*) or (sustainable aviation fuel) and luchtvaart* or vliegsector	1091		Articles demonstrate little relevance in content Excessive amount of articles Consistent development of articles over time
2	atleast2(biokerosine or biobrandstof* or (synthetisch* w/s kerosine) or (synthetisch* w/s brandstof*) or (duurza* w/s kerosine) or (duurza* w/s brandstof*) or (SAF w/s duurza*) or (sustainable aviation fuel)) and luchtvaart* or vliegsector or vliegen or luchthaven or vliegtuig	713		Increased relevance in content yet an excessive amount of articles Search string requires more keywords to enhance comprehensiveness
3	atleast2(kerosine or vliegtuigbrandstof or (brandstof w/s vlieg*) or (brandstoffen w/s vlieg*) or (fossiel* w/s kerosine) or (fossiel* w/s brandstof*) or (aardolie w/s kerosine) or (brandstof* w/s aardolie) or (ruw* w/s olie w/s kerosine) or (ruw* w/s olie w/s brandstof*) or biokerosine or biobrandstof* or (synthetisch* w/s kerosine) or (synthetisch* w/s brandstof*) or (duurza* w/s kerosine) or (duurza* w/s brandstof*) or (SAF w/s duurza*) or (sustainable aviation fuel)) and luchtvaart* or vliegsector or vliegen or luchthaven or vliegtuig	1870		Excessive amount of articles

4	atleast2(kerosine or vliegtuigbrandstof or (brandstof w/s vlieg*) or (brandstoffen w/s vlieg*) or (fossiel* w/s kerosine) or (fossiel* w/s brandstof*) or (aardolie w/s kerosine) or (brandstof* w/s aardolie) or (ruw* w/s olie w/s kerosine) or (ruw* w/s olie w/s brandstof*) or biokerosine or biobrandstof* or (synthetisch* w/s kerosine) or (synthetisch* w/s brandstof*) or (duurza* w/s kerosine) or (duurza* w/s brandstof*) or (SAF w/s duurza*) or (sustainable aviation fuel)) and atleast2(luchtvaart* or vliegsector or vliegen or luchthaven or vliegtuig)	1355		Increased relevance in content yet an excessive amount of articles Search string requires more keywords to enhance comprehensiveness Consistent development of articles over time
5	atleast3(kerosine or vliegtuigbrandstof or (brandstof w/s vlieg*) or (brandstoffen w/s vlieg*) or (fossiel* w/s kerosine) or (fossiel* w/s brandstof*) or (aardolie w/s kerosine) or (brandstof* w/s aardolie) or (ruw* w/s olie w/s kerosine) or (ruw* w/s olie w/s brandstof*) or biokerosine or biobrandstof* or (synthetisch* w/s kerosine) or (synthetisch* w/s brandstof*) or (duurza* w/s kerosine) or (duurza* w/s brandstof*) or (schone w/s kerosine) or (schone w/s brandstof*) or (circulaire kerosine) or (circulaire brandstof*) or (groen* w/s kerosine) or (groen* w/s brandstof*) or (SAF w/s duurza*) or (sustainable aviation fuel)) and atleast2(luchtvaart* or vliegsector or vliegen or luchthaven or vliegtuig)	809		Increased relevance yet an excessive amount of articles
6	atleast4(kerosine or vliegtuigbrandstof or (brandstof w/s vlieg*) or (brandstoffen w/s vlieg*) or (fossiel* w/s kerosine) or (fossiel* w/s brandstof*) or (aardolie w/s kerosine) or (brandstof* w/s aardolie) or (ruw* w/s olie w/s kerosine) or (ruw* w/s olie w/s brandstof*) or biokerosine or biobrandstof* or (synthetisch* w/s kerosine) or (synthetisch* w/s brandstof*) or (duurza* w/s kerosine) or (duurza* w/s brandstof*) or (schone w/s kerosine) or (schone w/s brandstof*) or (circulaire kerosine) or (circulaire brandstof*) or (groen* w/s kerosine) or (groen* w/s brandstof*) or (SAF w/s duurza*) or (sustainable	575		Increased relevance yet an excessive amount of articles Search string requires more keywords to enhance comprehensiveness

	aviation fuel)) and atleast2(luchtvaart* or vliegsector or vliegen or luchthaven or vliegtuig)			
7	atleast4(kerosine or vliegtuigbrandstof or (brandstof w/s vlieg*) or (brandstoffen w/s vlieg*) or (fossiel* w/s kerosine) or (fossiel* w/s brandstof*) or (aardolie w/s kerosine) or (brandstof* w/s aardolie) or (ruw* w/s olie w/s kerosine) or (ruw* w/s olie w/s brandstof*) or biokerosine or biobrandstof* or (synthetisch* w/s kerosine) or (synthetisch* w/s brandstof*) or (duurza* w/s kerosine) or (duurza* w/s brandstof*) or (biologisch* w/s kerosine) or (biologisch* w/s brandstof*) or (alternatie* w/s kerosine) or (alternatie* w/s brandstof*) or kunstkerosine or (milieuvriendelijk* w/s kerosine) or (milieuvriendelijk* w/s brandstof*) or (hernieuwba* w/s kerosine) or (hernieuwba* w/s brandstof) or (elektrisch w/s kerosine) or (elektrisch w/s brandstof) or (elektrisch w/s vlieg*) or (waterstof w/s kerosine) or (waterstof w/s biobrandstof*) or (schone w/s kerosine) or (schone w/s brandstof*) or (circulaire kerosine) or (circulaire brandstof*) or (groen* w/s kerosine) or (groen* w/s brandstof*) or (SAF w/s duurza*) or (sustainable aviation fuel)) and atleast3(luchtvaart* or vliegsector or vliegen or luchthaven or vliegtuig)	556		Articles demonstrate acceptable relevance in content Acceptable comprehensiveness of search string Consistent development of articles over time
8	atleast5(kerosine or vliegtuigbrandstof or (brandstof w/s vlieg*) or (brandstoffen w/s vlieg*) or (fossiel* w/s kerosine) or (fossiel* w/s brandstof*) or (aardolie w/s kerosine) or (brandstof* w/s aardolie) or (ruw* w/s olie w/s kerosine) or (ruw* w/s olie w/s brandstof*) or biokerosine or biobrandstof* or (synthetisch* w/s kerosine) or (synthetisch* w/s brandstof*) or (duurza* w/s kerosine) or (duurza* w/s brandstof*) or (biologisch* w/s kerosine) or (biologisch* w/s brandstof*) or (alternatie* w/s kerosine) or (alternatie* w/s brandstof*) or kunstkerosine or (milieuvriendelijk* w/s kerosine) or (milieuvriendelijk* w/s	439		Articles demonstrate acceptable relevance in content Manageable amount of articles for coding after manual filtration Acceptable comprehensiveness of search string

	brandstof*) or (hernieuwba* w/s kerosine) or (hernieuwba* w/s brandstof) or (elektrisch w/s kerosine) or (elektrisch w/s brandstof) or (elektrisch w/s vlieg*) or (waterstof w/s kerosine) or (waterstof w/s biobrandstof*) or (schone w/s kerosine) or (schone w/s brandstof*) or (circulaire kerosine) or (circulaire brandstof*) or (groen* w/s kerosine) or (groen* w/s brandstof*) or (SAF w/s duurza*) or (sustainable aviation fuel)) and atleast3(luchtvaart* or vliegsector or vliegen or luchthaven or vliegtuig)			Consistent development of articles over time
9	atleast6(kerosine or vliegtuigbrandstof or (brandstof w/s vlieg*) or (brandstoffen w/s vlieg*) or (fossiel* w/s kerosine) or (fossiel* w/s brandstof*) or (aardolie w/s kerosine) or (brandstof* w/s aardolie) or (ruw* w/s olie w/s kerosine) or (ruw* w/s olie w/s brandstof*) or biokerosine or biobrandstof* or (synthetisch* w/s kerosine) or (synthetisch* w/s brandstof*) or (duurza* w/s vliegtuigbrandstof*) or (duurza* w/s brandstof*) or (biologisch* w/s kerosine) or (biologisch* w/s brandstof*) or (alternatie* w/s kerosine) or (alternatie* w/s brandstof*) or kunstkerosine or (milieuvriendelijk* w/s kerosine) or (milieuvriendelijk* w/s brandstof*) or (hernieuwba* w/s kerosine) or (hernieuwba* w/s brandstof) or (elektrisch w/s kerosine) or (elektrisch w/s brandstof) or (elektrisch w/s vlieg*) or (waterstof w/s kerosine) or (waterstof w/s biobrandstof*) or (schone w/s kerosine) or (schone w/s brandstof*) or (circulaire kerosine) or (circulaire brandstof*) or (duurza* w/s kerosine) or (groen* w/s kerosine) or (groen* w/s brandstof*) or (SAF w/s duurza*) or (sustainable aviation fuel)) and atleast3(luchtvaart* or vliegsector or vliegen or luchthaven or vliegtuig)	347		Substantial amount of relevant articles omitted Insufficient amount of articles for coding after manual filtration
10	atleast5(kerosine or vliegtuigbrandstof or (brandstof w/s vlieg*) or (brandstoffen w/s vlieg*) or (fossiel* w/s kerosine) or (fossiel* w/s brandstof*) or	384		Substantial amount of relevant articles omitted

	(aardolie w/s kerosine) or (brandstof* w/s aardolie) or (ruw* w/s olie w/s kerosine) or (ruw* w/s olie w/s brandstof*) or biokerosine or biobrandstof* or (synthetisch* w/s kerosine) or (synthetisch* w/s brandstof*) or (duurza* w/s kerosine) or (duurza* w/s brandstof*) or (biologisch* w/s kerosine) or (biologisch* w/s brandstof*) or (alternatie* w/s kerosine) or (alternatie* w/s brandstof*) or kunstkerosine or (milieuvriendelijk* w/s kerosine) or (milieuvriendelijk* w/s brandstof*) or (hernieuwba* w/s kerosine) or (hernieuwba* w/s brandstof) or (elektrisch w/s kerosine) or (elektrisch w/s brandstof) or (elektrisch w/s vlieg*) or (waterstof w/s kerosine) or (waterstof w/s biobrandstof*) or (schone w/s kerosine) or (schone w/s brandstof*) or (circulaire kerosine) or (circulaire brandstof*) or (groen* w/s kerosine) or (groen* w/s brandstof*) or (SAF w/s duurza*) or (sustainable aviation fuel)) and atleast4(luchtvaart* or vliegsector or vliegen or luchthaven or vliegtuig)		Insufficient amount of articles for coding after manual filtration

9.2 Appendix B: Coding scheme used in this study including additional information on actor and concept codes where deemed necessary

Level 1 code	Level 2 code	Level 3 code	Level 4 code	Level 5 code	Additional code information
Actors					Actors within the (Dutch aviation) industry.
	Affiliates				Associated entities or organizations involved in projects, programs or initiatives.
		Advisory Boards			Boards offering expert guidance to industry stakeholders, for instance on strategic decisions or policy matters. e.g. Accenture
		Associations			Associations from outside the industry. e.g. Algemene Nederlandse Wielrijdersbond (ANWB)
		Companies			Companies from both within and outside the industry, for instance participating in programs. e.g. Arcadis
			DSGC		Dutch Sustainable Growth Coalition
		Foundations			Foundations providing financial support and resources, for instance for initiatives and projects within the industry. e.g. Nationaal Groeifonds
	Airlines				
		Airline Companies			
			KLM		Koninklijke Luchtvaart Maatschappij
			Transavia		
			TUI		TUI fly Formerly known as Arkefly.

	Aviation Sector				The aviation sector in its entirety.
	Environmental Organizations				
		Europe Climate Foundation			
		Extinction Rebellion			
		Greenpeace			
		Milieu Centraal			
		Milieudefensie			
		Milieufederatie			
		Natuur & Milieu			
		Transport & Environment			
		WNF			Wereld Natuur Fonds
	Fuel Producers				
		AFF			Algae Food & Fuel
		AlgaeLink			
		AlgaePARC			
		AltAir			
		BTG			Biomass Technology Group
		DSM			Dutch State Mines
		Dynamic Fuels			
		Neste			
		Shell			
		Synkero			
	Government				
		Cabinet			The Dutch Cabinet in its entirety.
			Ministries		Particular ministries within the Dutch Cabinet. e.g. Ministerie van Infrastructuur en Waterstaat (IenW)
		ILT			Inspectie Leefomgeving en Transport
		International Bodies			
			European Commission		
			European Parliament		
			ICAO		International Civil Aviation Organisation

			OECD		The Organization for Economic Co-operation and Development
		Political Parties			Dutch Political parties that are not part of the Cabinet. e.g. GroenLinks
	Infrastructure Companies				Infrastructure companies providing services and resources, for instance for the development or maintenance of physical structures and systems. e.g. Oiltanking
	International Industry Associations				
		EREA			Association of European Research Establishments in Aeronautics
		IATA			International Air Transport Association
	Knowledge Institutions				
		Breda University Of Applied Sciences			
		CBBE			Centre for Biobased Economy
		CSTT			Centre for Sustainable Tourism and Transport
		Differ			Dutch Institute for Fundamental Energy Research
		Ecofys			
		Erasmus Universiteit Rotterdam			
		NLR			Nederlands Lucht- en Ruimtevaartcentrum
		PBL			Planbureau voor de Leefomgeving
		PNL			Platform Nederlandse Luchtvaart Formerly known as Platform Duurzame Luchtvaart.

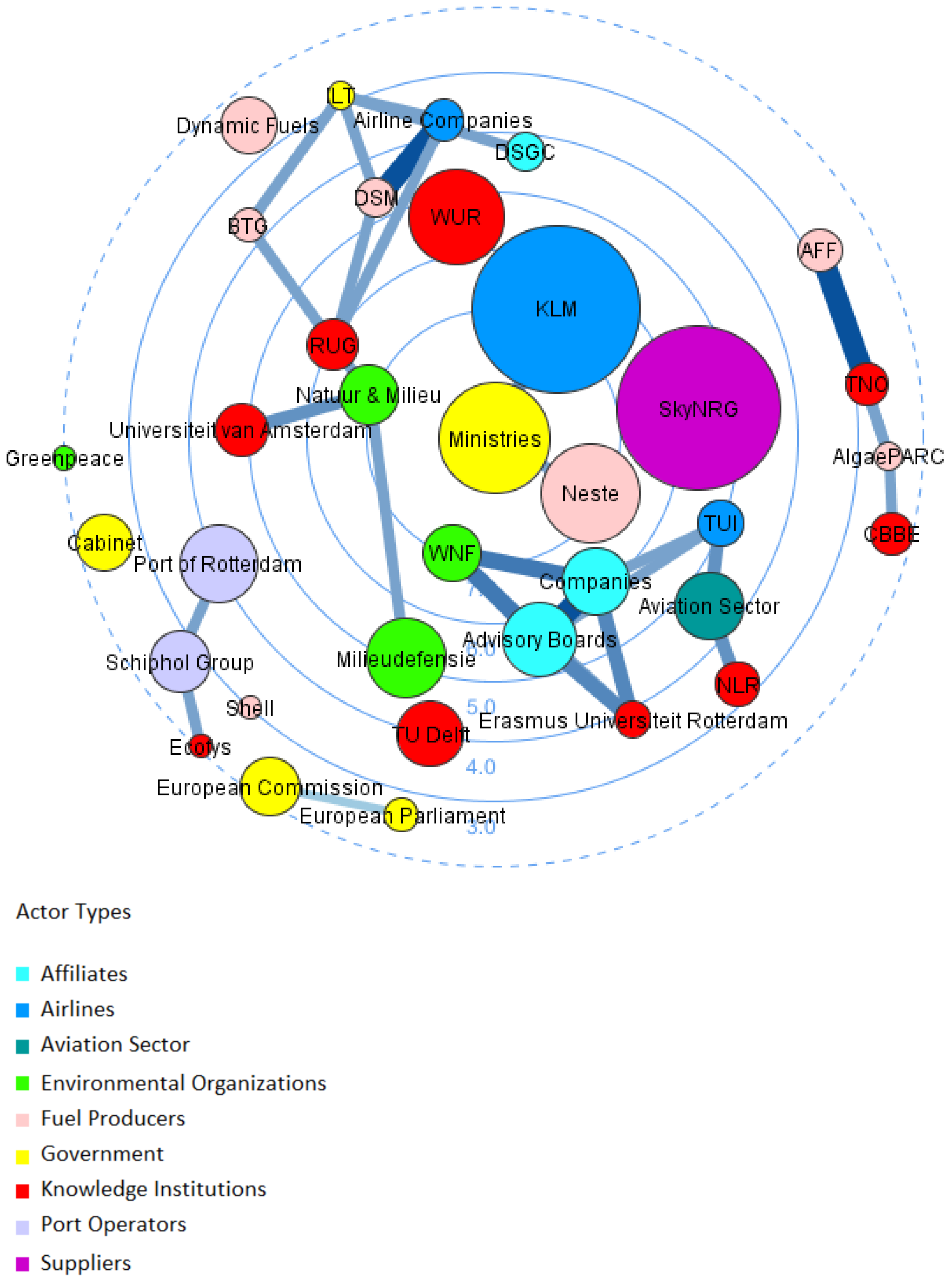
		RUG			Rijksuniversiteit Groningen
		SEO			SEO Economisch Onderzoek
		TNO			De Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek Includes Energieonderzoek Centrum Nederland (ECN).
		TU Delft			Technische Universiteit Delft
		TU Eindhoven			Technische Universiteit Eindhoven
		Universiteit Twente			
		Universiteit Utrecht			
		Universiteit Van Amsterdam			
		WUR			Wageningen University & Research
	Manufacturing Companies				Aircraft component manufacturers producing parts and equipment used in the construction and maintenance of aircrafts. e.g. Fokker Technologies
	Port Operators				
		Groningen Seaports			
		Port Of Amsterdam			
		Port Of Rotterdam			
		Schiphol Group			Koninklijke Schiphol Group
	Suppliers				Fuel suppliers responsible for providing aviation fuel to airlines and other aviation operators.
		AFS			Aircraft Fuel Supply
		SkyNRG			

	Travel Organizations				e.g. Sunweb
Concepts					Concepts within two distinct paradigms.
	Conventional Paradigm				Technological and institutional elements related to fossil-fuel based aviation fuel, representing rather traditional modes of thinking, operation and problem-solving.
		Financial Incentives (c)			Financial incentives related to fossil-fuel based aviation fuel. e.g. subsidies, monetary rewards, tax credits, withdrawal of subsidies, air travel tax, CO2-tax or excise duty
		Fuel Types (c)			
			Kerosene (c)		
		Governance Arrangements (c)			Governance arrangements related to fossil-fuel based aviation fuel. e.g. laws, regulations, policy objectives, guidelines, restrictions, compensations and standards.
		Infrastructure Types (c)			
			Fuel Terminal (c)		
			Pipeline (c)		
			Refinery (c)		
			Ship (c)		
		Reports (c)			
		Values (c)			Fundamental beliefs, principles and stances towards the 'Conventional Paradigm'.
	Sustainable Paradigm				Technological and institutional elements related to SAF, representing ways of

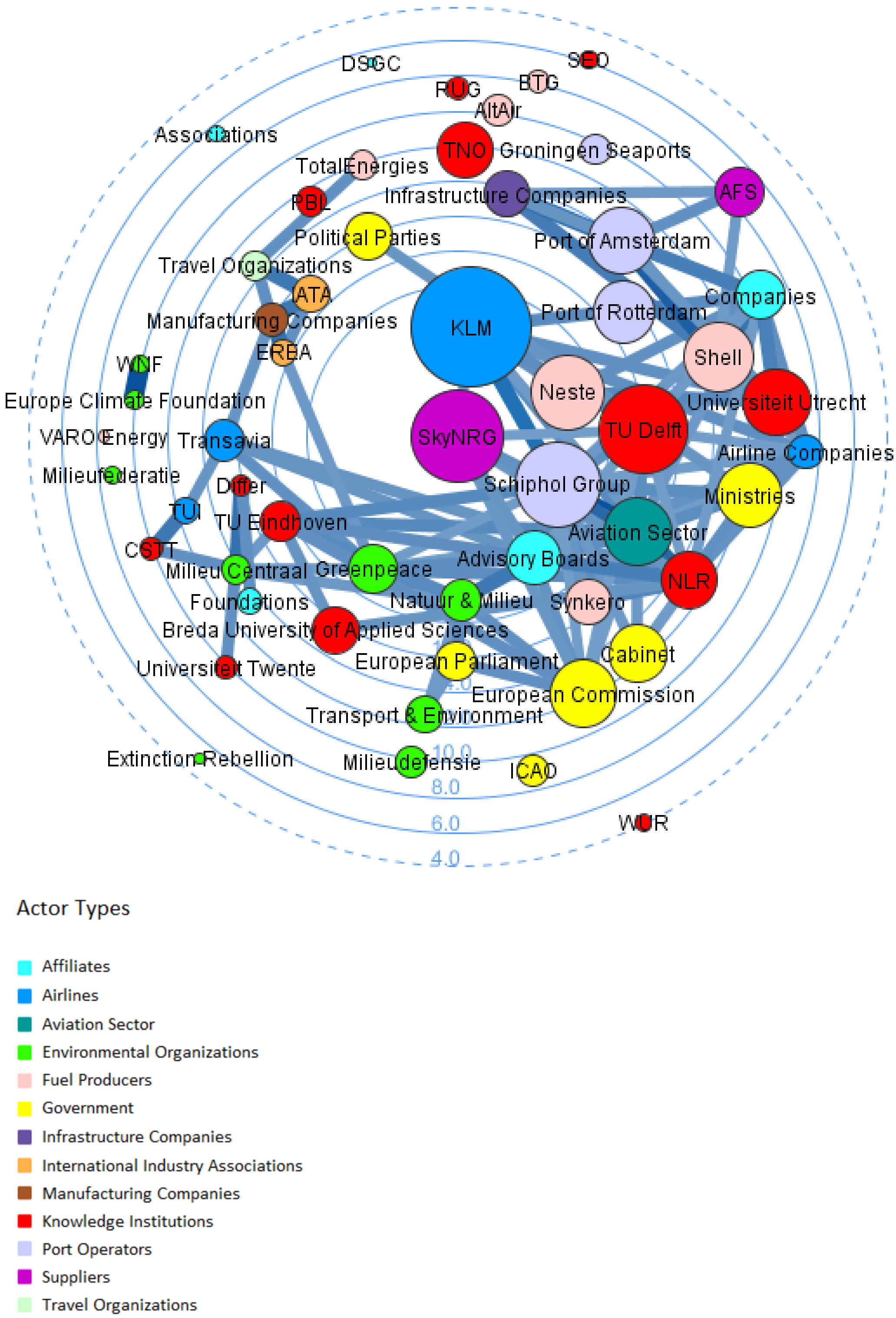
					thinking, working and problem-solving that focus on sustainable development within the Dutch aviation sector.
		Financial Incentives (s)			Financial incentives related to SAF. e.g. subsidies, monetary rewards, tax credits, withdrawal of subsidies, air travel tax, CO2-tax or excise duty
		Fuel Types (s)			
			Biokerosene (s)		
				First-generation Biokerosene (s)	
				Second-generation Biokerosene (s)	
				Third-generation Biokerosene (s)	
			Synthetic Kerosene (s)		
		Governance Arrangements (s)			Governance arrangements related to SAF. e.g. laws, regulations, policy objectives, guidelines, restrictions, compensations and standards.
		Infrastructure Types (s)			
			Fuel Terminal (s)		
			Pipeline (s)		
			SAF Production Facility (s)		
			Ship (s)		

			Tanker Truck (s)		
		Reports (s)			
		Values (s)			Fundamental beliefs, principles and stances towards the 'Sustainable Paradigm'.

9.3 Appendix C: Actor congruence network of Phase II including only links with Jaccard index > 0.5



9.4 Appendix D: Actor congruence network of Phase III including only links with Jaccard index > 0.5



9.5 Appendix E: Part of the coding scheme used in this study to get an indication of how the levels of codes under respectively Actors and Concepts look in NVivo

Name	Files	References	Modified on	Modified by	Classification
Actors	0	0	1/15/2024 2:13 PM	NTK	
Affiliates	14	57	2/27/2024 1:47 PM	NTK	
Advisory Boa	14	19	2/2/2024 12:09 PM	NTK	
Associations	1	2	5/18/2024 6:25 PM	NTK	
Companies	21	30	2/7/2024 8:17 PM	NTK	
DSGC	3	3	1/29/2024 10:59 PM	NTK	
Foundations	3	3	2/8/2024 1:34 PM	NTK	
Airlines	125	235	5/18/2024 6:27 PM	NTK	
Airline Comp	19	20	5/18/2024 6:29 PM	NTK	
KLM	107	198	2/8/2024 3:27 PM	NTK	

Name	Files	References	Modified on	Modified by	Classification
Concepts	0	0	1/15/2024 2:05 PM	NTK	
Conventional Pa	142	273	2/6/2024 2:07 PM	NTK	
Financial Inc	15	21	2/9/2024 12:44 AM	NTK	
-	11	15	2/9/2024 11:41 AM	NTK	Sentiment
+	4	4	2/9/2024 11:36 AM	NTK	Sentiment
Fuel Types	92	117	3/13/2024 3:58 PM	NTK	
-	35	37	2/9/2024 11:44 AM	NTK	Sentiment
+	70	79	2/9/2024 11:45 AM	NTK	Sentiment
Governance	14	14	2/6/2024 2:07 PM	NTK	