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A cognitive mapping approach to analyse stakeholders’ perspectives on sustainable aviation fuels

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ABSTRACT

Despite sustainable aviation fuel (SAF) provides a viable option to decarbonise global aviation, the fuel transition to the commercial level is stagnant. Our paper investigates the key barriers and opportunities in upscaling the SAF consumption perceived by industrial stakeholders along the SAF supply chain. The primary interview data of stakeholders is analysed using the cognitive mapping approach. We contribute to the literature by developing multi-layer cognitive maps of stakeholder groups followed by a composite map to investigate the SAF development process. Though there is a common goal of lowering emissions, producers, airlines, distributors, and governmental and other advocating agencies map their distinct paths. Furthermore, our composite cognitive map presents strategic levers which are critical in SAF development and are shared by all shareholder groups. Such an understanding of SAF development is instrumental in developing progressive strategies for expediting the transition to SAF that balances environmental sustainability and economic benefits.

1. Introduction

Commercial aviation relies on liquid fuels derived from crude oil (Zhang et al., 2020). Due to the significant growth in air travel demand, fossil-based aviation fuel consumption is expected to increase 2–3% annually (Wang et al., 2019a). The International Air Transport Association (IATA) estimates that global air passengers may reach 7.2 billion by 2035 (O’Connor et al., 2019). Consequently, global aviation may contribute 4.6–20.2% of carbon dioxide (CO₂) emissions by 2050 (Staples et al., 2018). Though the COVID-19 pandemic has halted the aviation industry’s growth with a 54.2% drop in passenger travel (Mazareanu, 2020), the long-term negative consequences of using fossil-based jet fuel could remain significant (Chiaramonti & Maniatis, 2020). In this context, the goal set by IATA to reduce the industry’s net carbon emissions by 50% in 2050, compared to 2005 levels, while achieving a carbon-neutral growth from 2020 onwards is still highly relevant (IATA, 2015).

It is believed a portfolio of strategies is required to mitigate the negative impact of using petroleum-based aviation fuels (IRENA,
under way to assess commercial long-distance flights (Schäfer et al., 2019). Electrification seems to be a viable option to reduce emissions for the short-haul aeroplane category; research is currently underway to assess commercial long-distance flights (Schäfer et al., 2019). However, electric aircraft may not be commercially available until well after 2050 (IRENA, 2017). On the operational side, aviation’s CO₂ and non-CO₂ emission effects can be limited by improving air traffic management through optimised take-off and landing routines and planning optimised flight paths (IRENA, 2017), or by reduced air-travel volumes compared to business-as-usual (Larsson et al., 2019). Due to lack of readiness in alternatives and/or the insufficient potential to achieve net-zero carbon targets, liquid fuels seem to continue to play a significant role in aviation (Gegg et al., 2014; Gegg & Wells, 2017). Therefore, liquid hydrocarbons from waste or renewable sources (biological or non-biological resources) when blended with conventional fossil-based jet fuel, known as sustainable aviation fuel (SAF)¹ provide a viable alternative (Kallbekken & Sælen, 2021; Vela-García et al., 2020). These low carbon fuels produced following ASTM International approved pathways² have “drop-in” characteristics with specifications and compatibility with the combustion behaviour of conventional jet fuel. This means, that SAF unrestrictedly fulfills the stringent fuel performance requirement of a jet engine and poses almost no disruption to the existing aviation jet fuel supply (Zhang et al., 2020). SAF is now considered to be a medium-term solution for combating emissions and reducing jet fuel fossil jet fuel dependency (The Royal Society, 2019). For example, 20% of SAF inclusion may make a substantial impact on commercial aviation emission by 2030 (de Jong et al., 2017).

Despite the suitability and reliability of SAF have been proven, its use in commercial aviation remains extremely low with less than 1% of total conventional jet fuel demand (IEA, 2019). The literature points several major challenges preventing the SAF uptake, such as lack of availability (Santos & Delina, 2021); limited production facility (Kousoulidou & Lonza, 2016), technical uncertainty (Zhang et al., 2020); the general public’s perception (Choi et al., 2018; Choi & Ritchie, 2014; Filimonau et al., 2018; Filimonau & Högström, 2017); the environmental impact of production and distribution (Kolosz et al., 2020; Michailos, 2018); policy uncertainty (Larsson et al., 2019; Nikita et al., 2019; Pechstein et al., 2020), and economic considerations (Bann et al., 2017; Witcover & Williams, 2020). The impetus of this research comes from the notion that despite the increasing number of flights made using SAF - starting from just one flight in 2008 to over 250,000 to date (IATA, 2020) - the fuel has not been able to make any significant strides in the aviation fuel chain. This allows exploration of the SAF uptake by focussing on the entire supply chain, rather than merely one aspect.

While most SAF studies focused on evaluating the SAF production pathways’ performance (e.g., identify the minimum selling price, environmental impact), limited attention has been paid on using stakeholder-based qualitative approaches to unblock the key barriers and opportunities in upscaling the production and consumption perceived by a diverse range of industry stakeholders (e.g., Gegg et al., 2015, Witcover and Williams, 2020).³ Our study aims to elicit, store, and handle the complexity revealed by stakeholders through an inquiry process that explores strategic issues in the SAF supply chain in an organised manner. The SAF supply chain is a complex network of entities involving fuel-producing companies, refineries making a specific SAF blend, distribution companies that bring SAF to commercial jet aeroplanes. Among all these entities there are those stakeholders who have the legitimacy (e.g., regulatory institutions) and those with high influence (e.g., climate advocacy groups) who can alter the course of the commercial aviation sector. All the stakeholders involved have their political views (sometimes conflicting too) and stakes in the development of the SAF supply chain. This situation becomes even more complex when we include the number of ways in which SAF can be produced, both chemical processes and feedstock-wise. Furthermore, SAF production and use have ramifications in other parts of society, like the environment, political and social sphere.

Our overarching research question is: ‘How to accelerate the uptake of SAF in commercial aviation as an alternative to fossil-based jet fuel?' A visual model based on the cognitive map approach (Eden, 1988)⁴ has been adopted because it shows the linkages between the issues, and contextualise and develop a unified understanding of a common goal between different stakeholders in making SAF commercial development, deployment and consumption. Through our study, we expect to gain insights into the following four sub-research questions (RQ):

RQ1: What are the key perceived benefits for SAF development, production, and uptake?
RQ2: What are the key perceived barriers for SAF development, production, and uptake?
RQ3. What are the interdependencies and interrelationships between benefits and barriers as perceived by the stakeholders?
RQ 4. Do multi-level cognitive maps help better recognise commonalities and conflicts among a diverse set of stakeholders?

In contrast to previous studies, our paper comprises four theoretical and methodological contributions on: 1) mapping individual stakeholder perspectives on SAF uptake that identifies and highlights linkages between factors (constraints, goals and options), 2) developing a stakeholder group strategic map that presents the sense of a viable business model for a specific stakeholder group, 3) presenting the global qualitative business strategy of SAF uptake, and 4) establishing a novel multi-level cognitive mapping approach to improve the understanding of the upscaling of SAF production and consumption problems. In addition, we also make major practical contributions by providing much needed empirical evidence on how different stakeholders perceive the way forward for SAF.

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¹ Other terms such as renewable aviation fuel, renewable jet fuel, alternative jet fuel, biojet fuel, and SAF have a similar intended meaning.
² For details on various pathways of SAF production readers are referred to Zhang et al. (2020).
³ For those studies that have adopted a semi-structured interview approach (e.g., Timmis, 2015; Gegg et al., 2014; 2015), they do not present either a stakeholder group and/or a global picture of SAF development, also do not present interconnectedness and interdependencies of concepts amongst stakeholders.
⁴ For details on structuring issues or problems using the cognitive map, the readers are referred to Eden (2004) and Bryson et al. (2004) while specific applications are reviewed in Section 2.2.
⁵ See for example, Timmis (2015) and Koistinen et al. (2019).
development and contribution to the goal of decarbonisation.

The rest of the paper is organised as follows. Section 2 describes the background of work highlighting previous work on SAF along with the suitability of the cognitive map approach. We then present the methodology we followed in Section 3 before presenting cognitive maps in Section 4. Section 5 discuss the findings while Section 6 concludes our study.

2. Background literature

In this section, we provide a review of the literature on the type of issues addressed and different techniques and methods used in SAF supply chain research. Next, we present a targeted review of the cognitive map approach used in the previous studies and its suitability with our research.

2.1. Sustainable aviation fuels (SAF)

The ASTM, an international body, has so far approved six pathways for SAF production including (i) Fischer-Tropsch (F-T) since 2009, (ii) hydropyrolysis esters and fatty acids (HEFA) since 2011, (iii) Synthesized Iso-Paraffinic (SIP) fuels from sugars, also known as DSHC (direct sugar-to-hydrocarbon) since 2014, (iv) alcohol to jet (ATJ) since 2016, and (v) F-T-Synthesized Paraffinic Kerosene with increased aromatic content (F-T-SPK/A), and (vi) catalytic hydrothermalysis jet (CHJ) in 2020 (ASTM, 2020). A major part of the SAF literature is associated with describing and evaluating SAF conversion technologies. Unlike fossil-based jet fuel, SAF can be produced in many different combinations from the feedstock and chemical process. For example, Wang et al. (2020) and Tan et al. (2020) present production technology to convert oilseeds to SAF; Chen et al. (2020a) use waste cooking oil; converting rice husks to SAF is presented by Chen et al. (2020b), and process design to obtain SAF by Michailos (2018). Similarly, novel ways of SAF production from algae and solar thermochemical conversion is presented by Guo et al. (2017) and Falter et al. (2020), respectively. Likewise, technical comparison of SAF production pathways has been provided by Zhang et al. (2020).

The main focus of most techno-economic studies is on identifying the cost or minimum selling price (MSP) of SAF. To find the most economical SAF production pathway for a specific client, the United States Department of Defence, Beal et al. (2021) evaluated nine different combinations of processes and feedstocks of SAF production. They found SAF generally cost more than fossil jet fuel whereas the forestry residue and waste oil pathways yielded the lowest costs ($US$0.92 and $US$0.82 per litre, respectively) among competing SAF production pathways. Bann et al. (2017) followed stochastic modelling to find the MSP of SAF based on a net present value approach. The MSP of SAF was estimated by Diederichs et al. (2016). They found SAF MSP to be 2–4 times higher than fossil-derived jet fuels. In another techno-economic analysis, de Jong et al. (2015) found none of the six pathways assessed was able to reach price parity with fossil-derived jet fuel. They recommend co-production of SAF with existing infrastructure to bridge the price gap. This strategy was verified by Byun and Han (2020) for cellulosic feedstock-derived fuel. They showed that a $US 2.90 per gasoline gallon equivalent can be achieved thus giving sufficient profit margin for production. Similarly, Geleynse et al. (2020) highlight SAF MSP between $US 6 to $US 8 per gallon can be achieved for the ATJ pathway produced from an integrated process utilising pulp mill assets. Furthermore, techno-economic analysis for SAF from camelina oil via hydro-processing was done by Li et al. (2018). Under specific production conditions, their analysis showed an MSP of SAF ranging from $US 0.40–$US 0.71 per litre with the most sensitivity to feedstock costs.

On the social side of SAF, Fillimonau et al. (2018), investigated tourists’ opinions about the use of SAF. They measured the perception of benefits and safety concerns of the public in Poland. Their findings pointed to a low level of awareness concerning SAF use and suggested the design of awareness campaigns to raise the SAF profile. Another exploratory study on environmental concerns of aviation and SAF use was done in the UK by Fillimonau and Högström (2017). This study exposed limited public understanding of the associated environmental benefits of using SAF. Similarly, challenges and opportunities for SAF adoption were highlighted by Chiaramonti (2019) and Smith et al. (2017) while the role of airports in supporting clean aviation was explored by Kivits et al. (2010). The Input-Output analysis approach, Wang et al. (2019c) investigated the contribution of SAF production to the Brazilian environment. The analysis revealed net positive socio-economic effects on employment and gross domestic product (GDP). As mentioned above, SAF is expensive to use, hence it becomes logical for an airline to raise their ticket price. This issue has opened the willingness-to-pay (WTP) line of inquiry of SAF research. WTP for higher ticket price for greener flying, using but not limited to SAF only was found for short-haul as opposed to long-haul flights (Rice et al., 2020). Their findings were in contrast to Seetaram et al. (2018) in which the public was willing to pay more for long-distance flights. Similarly, using a contingent valuation approach, business organisations were found to be willing to pay an 11.9% price premium for flights using SAF (Goding et al., 2018).

The environment side of SAF production has been dominated by studies adopting a Life Cycle Analysis (LCA) approach. O’Connell et al. (2019) considered GHG emission savings and energy efficiency in their study. Their analysis revealed that SAF conversion pathways using forest residues as feedstock is less energy-intensive and gives more environmental benefits. LCA of SAF production from Staples et al. (2018) revealed that US$ 12 billion would be needed to achieve 50% or less GHG emissions by mid-century. Besides considering multiple feedstocks and conversion processes, other studies have investigated a single feedstock and process assessment. An LCA study of SAF production using wood-based feedstock by Ganguly et al. (2018) found that such fuel produced can achieve a 78% improvement in global warming impact as compared to petroleum jet fuel. Similarly, LCA of SAF produced from microalgae feedstock using the hydrothermal liquefaction process, by Fortier et al. (2014), revealed that GHG savings are higher at wastewater treatment plants than at a refinery. Likewise, Seber et al. (2014) implemented LCA and found that yellow grease-derived SAF yields a lower MSP than SAF from tallow as a feedstock while both show more GHG savings in comparison to petroleum jet fuel. Most recently, based on input from aviation industry stakeholders, Ahmad et al. (2021) evaluated 11 SAF production pathways using a multi-method multi-criteria approach. They found that the economic and environmental impact of SAF production pathways are more critical as compared...
to technical and social impact, while the choice of a particular production pathway depends on a country’s local techno-economic and/or market conditions.

Our survey of the literature on the technical, social, environmental, and economic evaluation of SAF has been dominated by quantitative techniques and methods. We have seen limited attention on using stakeholder-based qualitative approaches such as interviews, workshops, surveys, to gauge views and opinions from a diverse range of SAF supply chain stakeholders. For those studies that have adopted a semi-structured interview approach, they have followed a qualitative analysis approach that does not present either a stakeholder group and/or a global picture of SAF development. For example, Koistinen et al. (2019) applied a stakeholder signalling theory approach to analysing stakeholders’ responses based on 12 semi-structured interviews. They found despite early engagement in SAF as a strategic business move, stakeholders were also concerned over the high cost of SAF use. Policy-related stakeholders were found conflicted; on one hand, they want SAF uptake to increase while, on the other, they were concerned with unintended consequences, such as deforestation. Likewise, Gegg et al. (2014; 2015), carried out in-depth interviews with global aviation stakeholders, to identify and examine the perceived factors affecting SAF market development. Using thematic analysis, they found the main driver for SAF use was emission reduction while high production cost, lack of policy support and uncertainty in sustainability criteria along with a reliable supply of feedstock comprised the major barriers. From a global to a more national level, Timmis (2015) used the grounded theory approach to evaluate the sustainable development of the UK aviation sector. The main stakeholders were airports and government/non-governmental bodies. The study found that stakeholders considered sustainable development as an integrated concept having technical, social, environmental, and economic dimensions. However, they emphasised the technological solutions to address and overcome environmental, economic, and social constraints. Furthermore, Gegg and Wells (2019) argued that technological issues are progressively being solved whereas wider issues of stakeholder and public perception have largely been ignored in the sustainable fuel debate. Through their investigation, they found conflicts among stakeholders impeding the sustainable fuel supply chain development and recommend improved communication. Within the qualitative regime by reviewing the literature, Kim et al. (2019) mapped the social and technical challenges in SAF development. They used a causal loop approach in identifying the system level impediments and potential ways to overcome them. For example, the lack of R&D in SAF technology development can be managed by public sector funding driven by public pressure to mitigate environmental degradation. Deane and Pye (2018) reviewed the SAF development status in the EU and its member states using policy documents as well as previously published research. In their discourse analysis, they draw attention to the high cost of production, policy uncertainty and poor policy awareness as the main challenges in SAF development.

Our paper aims to address these gaps in the literature that recognise the barriers and challenges in SAF development, but does not examine the interconnectedness and integrate beliefs towards a shared vision at multiple levels through a cognitive mapping approach.

2.2. Cognitive map approach

The cognitive map technique has been widely used in the management area to illustrate and explore the mental structures of individuals/groups involved. For example, in project management, Ackermann et al. (2014) used the cognitive mapping approach to elicit risks; meanwhile understanding the reasons for failures in large complex projects was done by Ackermann and Eden (2005). The former study relied on workshops to create detailed maps reflecting the wealth of participant perspectives present at the workshop without integrating them while the latter combined the individual stakeholder group cognitive maps. Furthermore, in strategic management, Silva et al. (2021) set out to measure small and medium-sized enterprise inclination to adopt the open innovation concept as a means to achieving business competitiveness. By involving top-level managers in a series of workshops, the authors developed a single cognitive map. Despite this study allowed the participants to gain a holistic view of the decision problem at hand, it masked the individual perspective of managers involved in the open innovation.

In marketing management, using the cognitive map approach, Brun et al. (2014) pointed out several new concepts created by the web-based environment and calls for simplicity and ease of the customer’s web experience. Three separate cognitive maps were made based on interviews with the experts to analyse the similarities and differences. However, these cognitive maps were not combined to see the overall visual presentation of the issue. In knowledge management, Spanellis et al. (2020) developed a dynamic model pivoting on a cognitive map of a new product development process. The study showed that organisations’ knowledge management capabilities change over time from knowledge sharing to knowledge creation. The authors developed six cognitive maps, one for each company. Each company’s map was a combination of individual maps of participants from the company. Note that no composite map was developed to show the overall perspective on the product development, but rather similarities and differences in knowledge management of all six companies was presented.

In health management, Rees et al. (2018) used cognitive maps based on stakeholder interviews to develop a novel framework in implementing innovations in primary health care services. For this, a multi-level cognitive map approach was employed. As such, individual cognitive maps were developed which were then consolidated into a single map. Although two different expert groups were involved, policymakers and clinicians, the multi-level cognitive maps did not present the mental model of each group separately. Rather, a consolidated map was presented. Furthermore, the cognitive map approach has been applied in supply chain management highlighting the areas where the blockchain innovation would make its contribution, in particular, providing visibility and traceability through the chain (Wang et al., 2019b). To develop cognitive maps, the authors used a coding approach to identify concepts emerging from individual stakeholder interviews. Later, individual maps were combined to get a strategic level map. This approach, like Rees et al. (2018) do not provide cognitive maps of stakeholders with a similar background.

Moreover, cognitive maps have also been frequently used as a tool for policy analysis. For example, Eden and Ackermann (2004) developed cognitive maps for the UK Home Office Prison Department. An initial map developed from literature was explored and
expanded in the workshop of stakeholders to highlight the goal, options and interrelated concepts aiming to improve prison services. This research highlighted the ownership of contribution in a map as a critical factor thus highlighting the need for developing each stakeholder’s cognitive map distinctively and then merging them for a unified understanding of the problem. In addition, Tanaka et al. (2020) leveraged the cognitive mapping approach for at national level policy development for the renewable energy transition. A cognitive map of each stakeholder group was developed and analysed. Though the study highlighted each stakeholder group’s primary interests and likelihood for restructuring of the political dynamics, a collective map representing the interrelations in achieving a common goal was not presented. In addition, Shaw et al. (2017) traced the chain of argument in the fragmented political discussion of Brexit. In a follow-up study, Shaw et al. (2019) highlighted the change in the national narrative on Brexit. Both these studies used publicly available secondary data for their analysis and developed cognitive maps for ‘Leave’ and ‘Remain’ groups which were later combined based on a particular theme.

In summary, an overview of cognitive mapping literature shows two main areas worth to be further explored. The first being, though a wide range of applications of cognitive mapping exists, there are no specific applications in the aviation sector. Secondly, there is a lack of presenting multi-level cognitive maps such that several individual stakeholder perspectives are combined to provide that stakeholder group’s perspective on the complex problem, and then several stakeholder groups maps are combined to deliver a consolidated global view map. Therefore, we opt for a multi-level cognitive mapping approach to gain an integrated representation leading to a better understanding (Ackermann, 2012) representing SAF stakeholders’ differing worldviews (Mingers, 2011).

3. Research methodology

With a wide range of stakeholders involved in the SAF supply chain, each having specific business objectives, working towards a common goal can be challenging. This situation calls for highlighting cross-organisational perspectives as well as understanding the interdependencies of factors involved. For dealing with such a ‘wicked problem’ and developing a shared understanding (Ackermann et al., 2020), there are several structured and rigorous but non-mathematical methods and methodologies available - collectively known as Soft OR or Problem Structuring Methods (PSMs). Prime examples of these methods are soft systems methodology (SSM), strategic options development and analysis (SODA) and the strategic choice approach (SCA) (Collins et al., 2019). Among the PSMs, SODA relies on the soft OR method of cognitive mapping (Mingers, 2011). Cognitive maps represent a mental model of decision-makers cognisance of their situation and enable them to develop strategies that, in turn, steer decisions in achieving their goal (Abuabara et al., 2018; Schafermicht, 2019).

In our research, to capture and preserve the diverse range of viewpoints from stakeholders involved in the SAF supply chain we developed a novel multi-level cognitive maps approach. Fig. 1 shows the three levels with individual stakeholder maps at the left, the micro-level; combined cognitive maps for each stakeholder group, the meso level; meanwhile, the global perspective SAF supply chain is presented at the macro-level.

There are three basic ways of eliciting expert opinion (Hwang and Lin, 1987): 1) questionnaire survey; 2) document coding, and 3) interviews. In this paper, we followed the last approach by conducting semi-structured interviews. A graphical summary of the proposed framework is depicted in Fig. 2.

Step 1. Stakeholder identification

Freeman and Reed (1983, p 89) define stakeholders as “those groups without whose support the organization would cease to exist”. We took a departure from a narrow, single organisation point of view of a stakeholder to a wider and more general point of view. In particular, we followed the power, legitimacy and urgency framework by Mitchell and Wood (1997). The reason for this approach was that our work looks at the entire SAF supply chain, which comprises many different players.

Initially, we categorised SAF supply chain stakeholders as government (including government ministries, regulators, and agencies); non-government (including academic, research and/or think-tank organisations, and professional services (i.e., energy consultants)); and industry (including SAF producers, aviation fuel handling companies, airport operations, airlines, and industry associations). However, based on internal project consultation and interaction with groups such as the Sustainable Aviation Fuels Special Interest Group (SAF SIG), Roundtable on Sustainable Biomaterials (RSB), and Department for Transport (DfT) we decided to group SAF supply chain stakeholders like producers, distributors, airlines and government and non-governmental organisations (Govt./NGOs) categories.

We followed the latest media for inviting participants for an interview call (see Appendix A1, Call for Interview Volunteers). To ensure a balanced number of interviewees from each stakeholder group, we reached out to specific invitations as well. As a result of our various outreach activities, (see Appendix A2), we obtained consent for interviews from 37 experts. For the validity and reliability of the results we ensured that the interviewees were: (i) mid to high-level position in their respective organisations, (ii) have rich knowledge of and experience with aviation and SAF, and (iii) are willing to commit to an interview. As a result, 25 interviews were conducted and 17 were finally used to develop cognitive maps. Appendix A3 shows the breakdown of interviewees by organisation

\[^6\] To avoid confusion for the readers and keep the consistency of terminology in the paper, causal mapping used in Shaw et al. (2017; 2019) is described as cognitive mapping.

\[^7\] For details on each PSM please refer to Rosenhead and Mingers (2001).

\[^8\] Our interviewee inclusion criteria is based on Wang et al. (2019b).

\[^9\] Note that in some cases, we have combined some of the interviews as we have interviewed more than one expert within the same organisation, and they have expressed similar views.
role and category. Interview participants have been anonymised by an alphanumeric code to retain their confidentiality.

**Step 2. Stakeholder interviews**

In this study, we opted for semi-structured interviews as it provides an effective data collection technique, especially when a new, emerging, or under-investigated area of interest is being focussed upon (Bogner et al., 2009), in our case SAF. Semi-structured interviews with individual respondents help minimise any polarisation effect that may arise in group judgment approaches, typical in a Delphi study (Bonaccorsi et al., 2020; Winkler & Moser, 2016). Interviewees were asked to express their professional perspective on SAF and not necessarily that of the organisation they were affiliated with.

We designed a set of questions based on academic literature on innovative and new technologies. Questions were validated by our project’s internal and external experts. Please refer to Appendix A4 for a sample of interview questions. Interviews were carried out on Skype, or by telephone call, or by face-to-face meeting, depending on the specific geographic and personal requirement. All the interviews were voice recorded with the consent of the interviewee.

**Step 3. Elicit information**

![Multi-level cognitive maps](image-url)  
**Fig. 1.** Multi-level cognitive maps.

![Research method for developing cognitive maps](image-url)  
**Fig. 2.** Research method for developing cognitive maps.
We developed and followed an interview protocol to utilise the time and ensure interview quality (see Appendix A5). Both researchers took notes while only one engaged in the interview process. Voice recorded interviews were later transcribed.

**Step 4. Development and analysis of stakeholder maps**

In this step, we structured the qualitative information from the interviews into a diagrammatic form - a cognitive map. A double validation approach has been adopted following Shaw et al. (2017) in structuring a cognitive map whereby one of the researchers uses the transcripts and notes taken during the interview to draw the maps. Next, the second researcher cross-checks all the individual stakeholder cognitive maps on the summary of an individual interview and verifies the correctness of the links made between the concepts. Furthermore, stakeholders were contacted to ensure the validity of maps developed-individual, group, and the final strategic level map.

**Step 5 development of a strategic stakeholder map**

In the previous step, we developed the cognitive maps of each interviewee. As we grouped interviewees, based on their affiliation, we set out to develop a strategic cognitive map for each group. Individual cognitive maps were then merged to help identify a group’s perspective on the complex problem of SAF uptake. To merge the maps into a single strategic cognitive-map of a stakeholder group we followed the four-step process laid out by Pidd (2009): 1) overlap similar concepts/nodes; 2) add extra links between the concepts/nodes used by the individual interviewee to bring forth any synergies or causalities; 3) conform that the strategic map preserves any of the individual map’s hierarchies of links; and, 4) analyse the strategic map for any loops, clusters and persuasive concepts.

### 4. Analysis of the cognitive maps

In this section, we first present the analysis of the cognitive maps of individual interviews within a stakeholder category. Our contention, here, is that each map identifies and describes the decision maker’s subjective beliefs of the issue under discussion (Swan, 1997). This is followed by an analysis of the stakeholder group’s cognitive map. In the end, a global cognitive map, developed by combining the stakeholders’ group cognitive maps into a composite one, is presented. Note here that extra caution had been taken while combining cognitive maps. This was to ensure that we preserve the individual stakeholder cognition into a group’s map and further development of a composite map. To stitch the individual maps together, we identified common concepts/nodes pointing to a similar idea as suggested by Eden and Ackermann (2004) and Pidd (2009). Further, as we used interview transcripts to draw maps, we did not assume any links to avoid biasedness in the map.

#### 4.1. Individual stakeholder perspective-micro level

To analyse a cognitive map we used the cognitive complexity measure and central construct identification recommended by Eden et al. (1992) and Eden (1994). The cognitive complexity measure is the ratio of arrows to concepts showing that interviewees are aware of multiple concerns surrounding the issue under discussion, as presented on the map (Eden, 2004). Likewise, a central construct is identified by counting the number of in-arrows (causes) and out-arrows (consequences) from each construct (node) indicating the ‘density’ (importance) of that construct in its immediate domain. Constructs with a high count (i.e., many ‘in-arrows’ and/or ‘out-arrows’) are considered more important.

| ID | Busy constructs                                                                 | ID | Busy constructs                                                                 |
|----|--------------------------------------------------------------------------------|----|--------------------------------------------------------------------------------|
| P1 | 2 check local availability of feedstock [7]                                   | P5 | 13 policy intervention [6]                                                       |
|    | 26 displace fossil source of fuel [6]                                         |    | 1 SAF dedicated production facility [6]                                          |
|    | 28 SAF production [6]                                                          |    | 20 amount of waste feedstock available [5]                                      |
|    | 19 govt. policy alignment [6]                                                  |    |                                                                                |
|    | 31 technology to be considered [6]                                             |    |                                                                                |
|    | 26 demand of SAF [5]                                                           |    |                                                                                |
|    | 14 integration of technologies [5]                                             |    |                                                                                |
|    | 17 societal cost of using fossil fuel [5]                                      |    |                                                                                |
| P2 | 30 share of SAF [8]                                                            |    |                                                                                |
|    | 15 availability of finance [7]                                                 |    |                                                                                |
|    | 5 feedstock is the biggest issue [5]                                           |    |                                                                                |
| P3 | 8 need technology-neutral policies [5]                                         |    |                                                                                |
|    | 13 building a plant [5]                                                        |    |                                                                                |
|    | 30 produce compatible SAF [5]                                                  |    |                                                                                |
|    | 29 reduce the risk of production [5]                                           |    |                                                                                |
| P4 | 17 raise SAF demand worldwide [9]                                              |    |                                                                                |
|    | 2 SAF production [8]                                                           |    |                                                                                |
|    | 3 use ASTM certified technologies [7]                                          |    |                                                                                |
|    | 9 there are no regulation to support the commercialisation of SAF [7]          |    |                                                                                |
|    | 18 need carbon reduction [6]                                                   |    |                                                                                |
|    | 12 constraints to production [5]                                               |    |                                                                                |
|    |                                                                                |    |                                                                                |

**Busy concept legend:** construct# construct name [# of links]
arrows) indicate potential important issues due to their high connectivity on the map (Ackermann & Alexander, 2016). Hereinafter, these constructs are called busy constructs. Due to space constraints, we cannot show the cognitive map of each interview. However, we will be presenting and discussing the cognitive complexity and busy constructs of each map within a stakeholder group.

4.1. Producers

The average number of constructs coming from the producers’ stakeholder group was 41 while, on average, 51 links were formed. Likewise, the cognitive complexity validating the ‘expert status’ of an interviewee was found to be 1.22. Appendix A6 summarises these statistics.

Table 1 summarises each interviewee’s busy constructs. Depending on the interviewee and their respective background, the number of constructs varied. For example, interviewee P1 presented the highest number of eight busy constructs followed by P4 and P6 each presenting six; P3 four while P2, P5 and P7 had three busy constructs each. Each interviewee’s busy constructs highlighted issues and constraints (or opportunities) that need to be addressed from the SAF producer perspective. The number of busy concepts shows the richness of the cognitive maps for each interviewee.

As we can see from Table 1, all interviewees have focussed on issues related to SAF production. Some expressed concerns with the choice of SAF production (for example P1), while others seem to be less worried about that, believing that there are many chemical processes (P6 construct 29) that also fulfil jet fuel criteria (P4 construct 3, use ASTM certified technologies) and lead to produce compatible SAF, as pointed out by P3 construct 30. However, feedstock to be used for SAF production (P6 construct 4) emerged as being the biggest issue (P2 construct 5). As sustainability is important for SAF production, interviewees focussed on biomass or waste streams of feedstock only and their availability. This is evident from check local availability of feedstock pointed out by P1 (construct 2) which will reduce the risk of production by P3 (construct 29).

One of the key challenges to boost the demand is related to the high production cost of SAF (P1 construct 26; P4 construct 17; P6 construct 5) and who will pay for the price difference (P7 construct 28). However, production cost could be lowered by the integration of technologies (P1 construct 14), while securing finance to build a SAF production plant (P2 construct 15; P5 construct 1 and P6 construct 15) might not be straightforward. On the other hand, several benefits of using SAF have also been highlighted. For example, P7 through construct 21 makes it explicit that SAF decrease the CO2 emissions of our system, while P4 takes SAF as a means of carbon reduction from the aviation sector. Also, P1 through construct 17, linked SAF environmental benefits by bringing the societal cost of using fossil fuel for aviation.

Though there were not many discussions around the social aspects of SAF, there seems to be a consensus of perception among producer stakeholder category on the need for a clear policy and legal frameworks. For instance, P1 called for governmental policy alignment (construct 19); P5 calls for policy intervention (construct 13); while P6 laments the slow pace of policy development (construct 9). Others, like P3, linked policies with technologies used for SAF production (construct 8) while P4 explained the goal of policies to commercialise SAF production technologies (construct 9).

4.1.2. Distributors

In the distributor stakeholder group, we mapped two interviews into cognitive maps. The average number of constructs coming from the distributors’ stakeholder group was 33 while, on average, 82 links were formed. The average cognitive complexity within this stakeholder group is 1.17. The respective constructs, links and complexity of each interview is presented in Appendix A6.

The distributor stakeholder category represented aviation fuel servicing companies that are responsible for ensuring aviation fuel gets into the fuel tanks. In this context, both interviewees cognitive maps presented busy constructs that relate to the demand and supply side of SAF. Distributor D1 regarded create a steady demand for SAF (construct 30) to be a key issue, which was mirrored by D2 as I think people really accept it (construct 19). For a distributor to provide SAF to airlines willing to fly on SAF (D1 construct 21) came out as an important issue to be considered, along with use SAF (D2 construct 13). Both interviewees’ cognitive maps revealed the price of SAF to be crucial, represented as busy construct 4, and 8 by D1 and D2, respectively. D1 highlighted limited availability of fuel as a busy construct while D2 linked agree to emission goals in the context of using SAF. Busy constructs of the distributor stakeholder category are presented in Table 2.

4.1.3. Airlines

The fours interviews were mapped individually in the airlines’ stakeholder category. Each airline has used SAF in past as part of a demonstration flight or is considering using it in future regularly. Note that all these airlines fly medium to long-haul flights. The average number of constructs and links for the airlines’ cognitive map was 45 and 52 respectively, giving a cognitive completion of 1.16. However, the cognitive map of interviewees A1 and A4 had a higher number of constructs and links than A2 and A3. This points to a larger number of related topics covered by them in comparison to A2 and A3. Appendix A6 provides the details on several constructs, links, and complexity for airline stakeholder group cognitive maps.

By elaborating on the busy constructs presented by the airline stakeholder group (Table 3), we can see that, except for A1, none focussed on the technology for SAF production. A4 pointed out a lack of awareness on the airline’s side as airlines who are not directly involved in SAF don’t know much about it (construct 39). Moreover, A4 suggested airlines develop consensus and common understating on SAF (construct 33).

There seems to be a consensus among airlines that the price of SAF is high with a dire need to reduce price gap with fossil jet (A2 construct 9); decrease to within a margin of jet fuel (A4 construct 60), and fuels at a price on a par with conventional fossil jet (A3 construct 10). However, it might be an easy task to lower the SAF price as it is regarded as a complex issue (A1 construct 58) and a difficult process in making SAF (A1 construct 9). Airlines are considering SAF as one of the options to decarbonize the sector, along with other...
measures such as - purchase carbon allowances (A4 constructs 1 and 65).

On the supply side, issues such as, do not have commercial-scale plants (A1 construct 11) were highlighted and reiterated by A2 as an important issue as have right scale of production (construct 33). SAF production facility capacity is found to be essential to ensure the availability of supply (A4 construct 26) that will satisfy the large SAF volume needed (A3 construct 19) so that airlines can buy & fly routinely (A3 construct 13). Environmental concerns were found to be a pressing issue on the cognitive maps of all airlines. This was evident in the busy contrast of A1 as reduce GHG emissions (construct 54), A2 construct 24 called for manage carbon emissions whereas A4 through its busy construct 9 suggested an offset mechanism for carbon emissions from the aircraft. Though not as busy a concept on A3’s cognitive map, CO₂ emissions were included as life cycle CO₂ savings per year.

Furthermore, airlines highlight the role customers will play in enabling a higher level of SAF usage. This led A4 to argue different types of people have entrenched perception (construct 29) as a busy construct. Similarly, A3 called to develop consumer awareness (construct 15). In terms of the policies, all airline stakeholder cognitive maps highlight the need for regulations to monitor SAF and policies to promote SAF (e.g., leverage combination of several policy factors, A2 construct 10), as it is believed the current measures “do not go as far as the industry requires” (A1).

In summary, airline cognitive maps revealed a wide range of topics, while the cost of using SAF, emissions from flying and customer perspective are the three main concerns perceived by the airline stakeholder group.

4.1.4. Government/NGO

In this category of the stakeholder group, we mapped four interviews into cognitive maps. The average number of constructs was 31 while, on average, 37 links were formed; the average cognitive complexity within this stakeholder group is 1.18. The respective, constructs, links and complexity of each interview are presented in Appendix A6.

The Government/NGO stakeholder category represented organisations that are broadly responsible for regulating the aviation industry, promoting SAF production, its market development and ensuring environmental sustainability. In this context, all four cognitive maps revealed policy to be the main issue to be dealt with. The busy constructs of policy has been the key (N1 construct 29); maintain policy stability (N2 construct 5); have policy in place (N4 construct 2) pointed to the critical role policy can play in SAF industry development. N3 recommended taking road transport sustainable fuel policies as a standard in developing the respective policies for the aviation sector (construct 12). The chemical process to produce SAF was found not to be among the busy constructs in this stakeholder group. However, ensuring a steady flow of feedstock was found to be an important issue such as secure sustainable feedstocks by N3 (construct 2), N1 construct 3, construct 16 by N4. Additionally, N4 expressed some concern that the choices of feedstock for SAF production may get pushback from the society (construct 17). Busy constructs of this stakeholder category are presented in Table 4.

To make SAF mainstream cognitive maps of the Government/NGO category, N1 construct 2 argued that to get the business case depends on the improve market economics (N1 construct 36) and was echoed by N2 construct 2, stimulate SAF industry. Likewise, N2 pointed out the need for all stakeholders to work together toward a common goal of promoting SAF (construct 20) to fulfill the need for decarbonising the aviation sector (N2 construct 14). On the demand side, N4’s construct 39 directed to enlarge SAF demand which is relatively minuscule at present. N1 believed the lack of demand could be handled through a significant offset agreement with airlines.

Together with the busy constructs, challenges were identified and highlighted, which need to be addressed to make SAF mainstream. In that regard, the major challenges were: (1) regulatory challenges, (2) cost of SAF, (3) demand side challenges, (4) technical challenges, (5) market development challenges, and the (6) environmental challenges. These challenges are illustrated in Table 5.

Table 2
Busy Constructs-Distributors.

| ID | Busy constructs                                                                 | ID | Busy constructs                                                                 |
|----|--------------------------------------------------------------------------------|----|--------------------------------------------------------------------------------|
| D1 | 4 bridge the price gap between SAF & conventional jet [7]                      | D2 | 13 use SAF [7]                                                                |
|    | 30 create a steady demand for SAF [6]                                         |    | 19 I think people really accept it [5]                                         |
|    | 16 limited availability of fuel [6]                                            |    | 12 agree to emission goal [5]                                                   |
|    | 21 airlines willing to fly on SAF [5]                                          |    | 8 reduce financial gap [5]                                                      |

Table 3
Busy construct-airlines.

| ID | Busy constructs                                                                 |
|----|--------------------------------------------------------------------------------|
| A1 | 42 technologies are in early stage of development [6]                         |
|    | 58 sharing cost is very complex [5]                                           |
|    | 45 cost of production [5]                                                     |
|    | 11 have commercial-scale SAF production plants [5]                           |
|    | 54 reduce GHG emissions [5]                                                   |
|    | 9 it is difficult to make jet fuel [5]                                        |
| A2 | 23 use SAF [6]                                                               |
|    | 9 reduce price gap with fossil jet [5]                                        |
|    | 33 have the right scale of production [5]                                     |
|    | 5 type of feedstock used is not important [5]                                |
|    | 10 leverage a combination of several policy factors [5]                      |
|    | 24 manage carbon emissions [4]                                                |
|    | 36 results in a competitive advantage [4]                                     |
| A3 | 13 airlines can buy & fly routinely [5]                                       |
|    | 10 fuels at a price on a par with conventional fossil jet [4]                |
|    | 19 need to be available at commercial volumes [4]                            |
|    | 15 develop consumer awareness [4]                                            |
| A4 | 9 offset mechanism for carbon emissions from the aircraft [8]                |
|    | 65 what ratio would be appropriate for us to move forward with SAF [7]       |
|    | 29 different types of people have entrenched perception [7]                 |
|    | 26 ensure the availability of supply [6]                                      |
|    | 66 decrease to within a margin of jet fuel [5]                               |
|    | 8 cost of carbon allowance [5]                                                |
|    | 39 airlines who are not directly involved in SAF do not know much about it [5]|
|    | 33 get a narrative that works across all sustainable aviation fuels [5]      |
|    | 1 purchase carbon allowances [5]                                             |


(construct 12).

In summary, busy construct analysis revealed that stakeholders in this category focus on legislation, market development, feedstock sustainability and raising the SAF profile for making it a viable option for decarbonising aviation.

4.2. Stakeholder group perspective - meso level

Our next goal is to provide an aggregate view of each stakeholder group. To achieve this goal, we developed a composite cognitive map of each stakeholder group by combining all individual maps. However, combining individual maps resulted in many duplicated constructs. To manage this, we followed the Pidd (2009) guidelines, presented in step 5 of our research methodology section above. Additionally, we used each stakeholder code (refer to Appendix A3. Interviewees’ Affiliation) to maintain their contribution and trace it to the source.

Firstly, we ascertained constructs that are central to a specific stakeholder group using the centrality analysis approach (Eden et al., 1992). While the busy construct approach is useful to analyse each interview map, the merits of the centrality approach are that it does not limit to the immediate domain of a construct and includes successive layers/domains. For each additional layer from the central construct, a diminishing weight function is applied. The centrality analysis identified the enablers which would lead to the agreed goal of the stakeholders. Furthermore, we identified feedback within the structure of the map forming a loop (Ackermann & Alexander, 2016; Eden, 2004). Loops are cyclical goals (Eden & Ackermann, 2013) that provide higher identification of dependency and causality between the constructs and their influences. Identification of loops provides a rich picture of the interviewee’s understanding of the topic under consideration. Though a loop diminishes the hierarchical structure of a cognitive map (Eden, 1994), collapsing the loop to a single construct preserves the cognitive maps’ hierarchal structure (Eden, 2004).

4.2.1. Producer stakeholder group cognitive map

Fig. 3 shows the combined cognitive map of the producer stakeholder group, which consisted of 56 constructs connected through 68 links.

The centrality analysis revealed the highest score of 22 and the lowest score of 1 for constructs. Recall that a higher score indicates a higher ability to assist in reaching the goal of reduce carbon emissions.

The top five enablers (boxed constructs in Fig. 3) with their respective scores as perceived by producers are: 1 ensure business profitability and sustainability (22); 26 develop SAF industry (20); 11 raise SAF demand worldwide (16); 21 prove the feedstock and technology works (15); 10 bring SAF in cost parity with fossil-jet (14); and, 9 produce compatible SAF (14). Furthermore, three negative goals were also found in the cognitive map (highlighted in red in Fig. 3). The first negative goal points to the risk of losing a license for a refinery if they fall short of the products they are authorised to produce (construct 35). For example, producing diesel with jet fuel. The second negative goal, construct 39, highlights the difficulty of securing finances in the refinery sector while the final one indicates investors’ inclination not to make small financial investments (construct 27).

Loop analysis revealed three loops existing in the producers’ stakeholder group combined cognitive map in Fig. 3, while produce compatible SAF (construct 9) is found to be the common construct showing the core of producers’ beliefs. Table 5 presents loops and their line of argument for the producers’ group. The orientation of these loops showed that loop 1 focuses on feedstock & production pathway match; loop 2 brings forth the issue of developing global SAF demand & industry development, and loop 3 links SAF demand with prices.

4.2.2. Distributor stakeholder group cognitive map

Fig. 4 shows the combined map in the distributor category consisting of 54 constructs connected through 65 links.

The centrality analysis revealed enablers that would help in achieving the goal of reduce carbon emissions and raise SAF market size, constructs 24 and 9 respectively. Two negative goals were also identified on the map (i.e., highlighted in red in Fig. 4) - having a global mandate is difficult and gives monopoly to waste oil to SAF producers, construct 45 and 18, respectively. The former relates to policy options while the latter to the producer of SAF.

The centrality analysis showed the highest score of 19 and the lowest score of 1 for the constructs. The top five enablers are: 1 bridge the price gap between SAF & conventional jet fuel (19); 2 alleviate limited availability of SAF (15); 19 pricing mechanism is confidential (12); 52 make customers pay the premium (11); 43 create a steady demand for SAF (11). Unlike the producers’ cognitive map in section 4.2.1, only one loop is found. This loop consists of constructs 49, 50 and 51. This loop presents the distributors’ perception of an unintended consequence of the government’s financial support in narrowing down the SAF and conventional jet price differential. This setup points to the distributors’ understanding that there is a limit to which government can provide financial support. However, this situation leads to exploring other ways of bridging the price gap, as presented by make customers pay the premium (construct 52).

4.2.3. Airline group cognitive map

The combined map in the distributor category consisted of 51 constructs connected through 61 links (see Fig. 5). The centrality analysis revealed enablers that would help in achieving the goal of commit to carbon reduction (construct 50).

10 For example, constructs that are directly connected to a central node are given a weight of 1. Constructs linked to the next layer are given a weight of 1/2. Similarly, the next layer is given a weight of 1/3, and so on.

11 Negative goals are end point constructs that are to be avoided (Bryson et al., 2004).
Table 4
Busy constructs-Government/NGO.

| ID | Busy constructs | ID | Busy constructs |
|----|-----------------|----|-----------------|
| N1 | 12 have offtake agreement with an airline (6) | N3 | 12 needs strong policy support like road transport (7) |
|    | 36 improve market economics (5) |     | 35 use SAF (6) |
|    | 29 policy has been the key thing (5) |     | 2 secure sustainable feedstocks (6) |
|    | 3 use the right match of technology & feedstock (5) |     | |
| N2 | 2 stimulate SAF industry (5) | N4 | 39 enlarge SAF demand (5) |
|    | 5 maintain policy stability (5) |     | 16 have unrestricted supply of feedstock (6) |
|    | 20 work together to achieve a common goal (5) |     | 17 pushback from the society (5) |
|    | 14 decarbonise aviation (5) |     | 2 have policy in place (6) |

The centrality scores range from 15 to 1 while the top five constructs are: 9 what ratios would be appropriate for us to move forward with SAF (15 scores); 1 pile up cynicism about aviation & environment (14); 29 monitor carbon emission from flights (13); 27 reduce the price gap with fossil jet (13); 7 use SAF (12) and control cost of producing SAF (11). A negative goal has also been identified: 51 create price differential for airlines.

Loop analysis showed the existence of five loops in the map – see Table 6. We find that loops 1 to 4 share some similarities; for example, loops 1 and 2 call for monitoring the emissions to piling up the social construct of cynicism about aviation and the environment, while loops 3 and 4 link monitoring carbon emissions and take the carbon allowances available to an airline into account. The distinguishing construct in these loops is whether SAF use (construct 8) is considered or conventional jet fuel (construct 28). These four loops emphasise the operational focus of the airlines’ stakeholder group as seen by the inclusion of tactical decisions of what would be appropriate for us to move forward with SAF (construct 9). Finally, the fifth loop on the map, comprising constructs 16, 17 and 26, sees the accumulation of SAF production capacity as a means of higher learning in the sector which would result in attracting more investors to further scale up the production capacity. This setup is seen as a way of decreasing the cost of SAF for airlines (construct 24).

4.2.4. Government/NGO stakeholder group cognitive map

The combined cognitive map for this category of stakeholders consisted of 54 constructs connected through 63 links (Fig. 6). The centrality analysis showed the highest score of 18 and the lowest score of 1 for constructs involved. The centrality analysis revealed enablers that would help in achieving the goal of decarbonise aviation sector (construct 49) for the Govt/NGO stakeholder group.

The top enablers including 16 scale up to commercial level (18 scores); 38 stimulate SAF industry (15 scores); 42 maintain policy stability (14 scores); improve the availability of SAF (13 scores); 40 improve market economics; 39 develop investors’ confidence, and 2 have significant offtake agreements with airlines.

Table 7 summarises the three loops in the map that we have identified. Firstly, loop 1 presents the idea of making innovations and improvements in the SAF production technology that will lead to higher SAF production. Loop 1’s focus is to get the developed production pathway licensed. A valid argument from this category of stakeholders is that no suitable policy can be developed to promote SAF use without a certified production pathway. This constraint stems from the higher level of safety requirements in the aviation sector. Secondly, loop 2 emphasises the production the technology development, and is evident from the three constructs: invest in R&D (construct 41); improve the technology side (construct 21), and right match of technology and feedstock (construct 18). All three constructs sit in a wider context of SAF production and achieving economies of scale.

Finally, loop 3 connects four enablers (16, 40, 39, and 38) such that improving market economics for SAF (construct 40), triggered by cost lowering measures (construct 55) and consensus in SAF use (construct 46), will lead to developing investors’ confidence (construct 39) which, in turn, will help energise the SAF industry (construct 38) and would finally manifest in production capacity augmentation (construct 16). This loop presents a high-level line of argument for the government/NGO stakeholder category signifying the importance of scaling up the SAF production to a commercial level.

4.3. Stakeholder global perspective - macro level

Having recognised the differences and similarities between individual stakeholder category cognitive maps, the next step is to combine them into one global map. The macro-level map represents the composite thinking of all stakeholders. As before, we followed the four-step process identified in section 3 (Step 5) in merging the maps. The resultant map had a total of 215 constructs. To maintain the readability of the strategic map, we have not included all the hierarchical details (see A7 for oval text in Fig. 7). Our objective is to identify all the enabler constructs (Table 8) and linkages between them (Fig. 7).

As seen in Fig. 7, there are two goals, develop SAF industry (construct 1) and decarbonise aviation sector (construct 17). These goals can be achieved by following the central constructs (enablers). The SAF industry can develop by making sure that stakeholders are involved undertake due diligence and ensure business profitability and sustainability (construct 16). While keeping other influences constant, business profitability has been identified to depend primarily on use the right mix of technology & feedstock (construct 29).

Further, the two goals are found to be linked to each other via scale up production to commercial level (construct 14). Enough SAF would not only alleviate limited availability of SAF (construct 12) but would also bring SAF in cost parity with fossil jet (construct 18) hence raise SAF demand worldwide (construct 23), thereby making airlines choose SAF over petroleum jet for the flights. However, there is a
Table 5
Identified loop line of argument: producers.

| Loop | Construct flow | Line of argument |
|------|----------------|-----------------|
| 1    | 1-6-7-8-9-21-26 | Feedstock & production pathway match |
| 2    | 1-6-7-8-9-10-22-11 | Global SAF demand & industry development |
| 3    | 9-10-22-11 | SAF price and demand nexus |
shortcoming. Due to the price difference with petroleum jet greater use of SAF creates a price differential for airline (construct 39) which leads to an anti-goal which endangers airlines’ financial status (construct 10).

Increasing SAF production capacity incurs delays both in decision-making as well as in construction, however, the cognitive map reveals that the price parity of SAF with petroleum jet fuel can be achieved by controlling the cost of producing SAF (construct 40). One way is to use feedstock with plentiful supply (construct 42) as well as consider negative-price feedstocks (construct 41). Another way to bring SAF production cost down is to co-process SAF with current fossil jet refineries (construct 65). However, both options are having adverse outcomes, these being: (1) give monopoly to waste oil producers and (2) refineries worry about losing their license if they co-process SAF with petroleum fuels, construct 38 and 32, respectively. In the same vein as SAF production, two related unintended consequences are: 1) investors’ inclination for larger SAF production capacities as they do not want to invest in small amounts (construct 57), and 2)
financial impediments they face in upgrading infrastructure to produce SAF blends (shown by construct 51, to be financed in refinery business is not easy).

Global composite maps include the public as an influential stakeholder. This is depicted by develop consumer awareness. The public influence the two crucial areas of environment and economic aspect of SAF development. In the former case, pile up cynicism about aviation and environment and in the latter case as an instrument to share the cost of using SAF thus minimising the anti-goal of endangers airlines financial status.

To ensure the validity and reliability of the results, we have disseminated our findings to interviewees, they were very excited to visualize the intersubjectivity of stakeholders conflicts and commonalities (Bryson et al., 2004), and the loop line of arguments. Participants’ responses feature the value our approach has brought to stakeholder way of thinking.

5. Discussion

Our research set out to explore how to accelerate the uptake of SAF in commercial aviation as an alternative to fossil-based jet fuel. We did so by exploring the answers to our four sub-research questions. The cognitive maps presented a strong stakeholder inclination to incorporate SAF into their business model and exploit the business opportunity (Bauen et al., 2020). They see engaging in SAF as their contribution to environmental protection and as a means to do business in a more social and environmentally responsible manner (Kosir et al., 2020) - thus answering RQ1 on the perceived benefits for SAF development, production and uptake. RQ2 has mainly been

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12 Regarding conflicts and commonalities one of the stakeholders responded as: “I’m surprised other airlines did not mention carbon markets as much as this along with mandate…” And, “…interesting to see what the other airlines said.”

13 For example, one of the stakeholders responded: “…I hadn’t thought about this subject like this before.”
addressed by the analysis of multi-level cognitive maps uncovered several challenges for SAF development, production, and uptake. These barriers range from technological complexities, access to finance, social acceptance, environmental as well as policy and regulatory. RQ3 has been responded via the identification and exploration of loops that exhibit interconnectedness and interactions between barriers and benefits. Finally, RQ4 has been answered by effectively been able to aggregate individual to group and to a global cognitive map developing a mutual understanding of the decision problem with minimal loss of information.

Next, we expand on some of the key findings that have been identified from our cognitive maps. Notably, we pinpoint how SAF demand and production can be articulated to achieve the decarbonisation and SAF market development goal. Firstly, by developing and evaluating mental models of multiple stakeholders, it became clear that for increasing the use of SAF in commercial aviation, lowering the production cost is necessary. The SAF cost is estimated to vary between two to five times the cost of conventional jet fuel (Bauen et al., 2020). This seems to be one of the main reasons airlines are reluctant to switch to SAF as fuel use cost is one of the biggest expenditures airlines incur (O’Connell et al., 2019). This finding is also in accordance with Kim et al. (2019) and Koistinen et al. (2019). Our cognitive maps revealed that bringing SAF in cost parity with fossil-based jet fuel is a convoluted issue due to links between the type of chemical process to produce SAF, process technical maturity, production capacity as well as feedstock availability and sustainability (for example, see Fig. 7).

Likewise, cognitive maps also exposed securing first-plant finance as a major hurdle to ramp up the SAF production capacity. To lower financial entry barriers, SAF production should be subsidised from a short to medium time frame. The policy of incentivising SAF production may lower the production cost necessary. The SAF cost is estimated to vary between two to five times the cost of conventional jet fuel (Bauen et al., 2020). This seems to be one of the main reasons airlines are reluctant to switch to SAF as fuel use cost is one of the biggest expenditures airlines incur (O’Connell et al., 2019). This finding is also in accordance with Kim et al. (2019) and Koistinen et al. (2019). Our cognitive maps revealed that bringing SAF in cost parity with fossil-based jet fuel is a convoluted issue due to links between the type of chemical process to produce SAF, process technical maturity, production capacity as well as feedstock availability and sustainability (for example, see Fig. 7).

Likewise, cognitive maps also exposed securing first-plant finance as a major hurdle to ramp up the SAF production capacity. To lower financial entry barriers, SAF production should be subsidised from a short to medium time frame. The policy of incentivising SAF production may lower the cost of fuel (Koistinen et al., 2019). In this regard, we propose setting up of scheme that would make securing debt or equity financing simple and underwritten by national governments. However, this is to be carefully devised as the government’s control in mitigating financial risk may result in abnormal market dynamics. Nevertheless, with a successful first-plant, investors’ confidence will be boosted, thereby easing access to finance for any subsequent projects ramping up production from demonstration scale to commercial scale (Witcover & Williams, 2020). Stakeholders also revealed that to produce a SAF blend, refineries face infrastructural as well as regulatory challenges. This insight has not been previously identified and discussed in the literature except that SAF production has been termed as a complex process (Gegg et al., 2015).
On the other hand, current regulations are not supportive in enabling multiple ways in which SAF can be carried to the wing of an aircraft (Doliente et al., 2020). In particular, the EU Emissions Trading Scheme (EU-ETS) requires the use of designated/separate logistics to bring SAF to the airport tank farm (Pechstein et al., 2020). The logistical constraint has also been seen as one of the reasons for the slow commercialisation of SAF. However, by securing long-term contracts between airlines and/or SAF producing/supplying companies, identified also by Nikita et al. (2019), not only can the production be ramped up but, also, regulations would develop, accommodating more SAF in the distribution system.

Our cognitive maps also showed that to facilitate the long-term stable development of SAF, there is a need to develop the supporting policy mechanisms related to the market system, including the capital market, fuel market and environmental commodity market. Therefore, a national or a regional policy framework consistent with international agreements would act as the orchestrator to provide the necessary legitimacy and influence to steer the complex ecosystem in which SAF resides. For instance, the Jet Zero Council in the UK, a government-industry partnership is striving to establish SAF production facilities to bring SAF to the commercial level (Jet Zero Council, 2021). Emission trading schemes, EU-ETS at a regional level, Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) at two international level regulatory approaches to limit aviation relevant emissions that have the potential for SAF commercialisation (Chiaramonti, 2019; Larsson et al., 2019). It is important to devise policy options of setting production/consumption quotas to match the right technology and feedstock, while simultaneously being conscious of technology lock-in risk (Bruce & Spinardi, 2018). Also, the industry is aware of the criticality of feedstock choice in ensuring the continued production of SAF.
Policymakers may consider providing financial incentives to feedstock producers to minimise the production uncertainty and ensure a stable supply of feedstock for SAF production (Klein et al., 2018; Ahmad et al., 2021).

Last, but not least, as an approach to reconcile stakeholders’ perspectives on SAF uptake and commercialisation, cognitive mapping proved as a valuable tool in highlighting the complexity innovation development faces in the real world. This approach effectively helped in acquiring each stakeholder perspective, and by merging and linking in the co-creation of shared knowledge (Pyrko et al., 2019). For example, prior studies (as in, Wang et al., 2019a) emphasized the lack of government financial support as a major challenge to SAF development, whereas our meso level cognitive map of the government/NGO stakeholder category (see Fig. 6) showed that such support in the long term could lead to market distortion.

6. Conclusion

Despite sustainable aviation fuels have the potential to decarbonise the aviation sector and alter the conventional jet fuel supply chain, the uptake of SAF has still been low. This can be attributed to several aspects (techno-economic, social, and environmental, to name a few), but at a strategic level, the challenge is how various stakeholders perceive impediments to a wider SAF adoption leading to its commercialisation. There is a lack of a comprehensive visual representation of stakeholders thinking about the problem in a structured manner following established specific rules of development.

6.1. Methodological contribution

In this paper, we interviewed 25 managers representing different organisations across the SAF supply chain. Unlike the more traditional forms of a qualitative inquiry, content and thematic analysis, adopted by Gegg et al., (2015; 2014), Timmis (2015), Deane and Pye (2018), Koistinen et al. (2019); Gegg and Wells (2019), we presented a visual exploration using a cognitive mapping approach. In this way, we introduced an additional approach of investigation previously unexplored in the aviation sector, particularly relating to SAF.

Our multi-level visual presentation is based on deep, tacit knowledge of stakeholders interviewed structured to establish the goals, options, assumptions. We developed and presented multi-level maps (micro, meso and macro) giving additional understanding to SAF deployment while maintaining the horizontal and vertical hierarchy structure (Smith & Shaw, 2019). Multi-level maps contributed to PSMs literature by showing that the diversity of individual maps can be grouped to develop a stakeholder group’s perspective and combining diverse stakeholders group’s perspectives at the global level helps avoid silo mentalities. As individual tends to frame things differently based on their perspectives, backgrounds, and experiences (Collins et al., 2019), our approach of interviewing each stakeholder individually resulted in gathering a ‘rich’ unbiased perspective on the problem. To this extent, we successfully mitigated the risk of individual/group dominance over others and individual/group non-participation in workshop settings.

6.2. Theoretical contribution

We gained valuable insights into how connections between these stakeholders’ roles and aspirations expedite SAF uptake. Each mapped interview identified perceived benefits and challenges to the technology’s deployment and further diffusion rendering their impact on supply chain development. Meso level cognitive maps signalled a strong domain focus of each stakeholder group. To be more specific, producers were more concerned with setting up and increasing production facilities while distributors, as intermediaries between producers and airliners, were worried about the limited market development of SAF. Airlines were found to be more operational inclined as their focus had been to try to balance the economics of SAF use, carbon emissions and public perception of their operations. Government and NGO sector stakeholders were more concerned with policy and regulations and making business entities responsible for market development. The global level merged map maintained the balance between unity and diversity of argument presented for SAF development by stakeholder groups. The broader economic consideration in production, supply, and usage of SAF is found to be the major concern, followed by technical and political issues.

Our findings contribute to the academic literature by exploring the strategic issues rather than simply highlighting the perceived challenges and opportunities as done in previous studies (e.g., Gegg et al., 2015; 2014, Timmis, 2015, Deane and Pye, 2018; Gegg and Wells, 2019). In addition, our work goes beyond by merely focusing on techno-economic, social regulatory and environmental, to name a few as highlighted in literature review. In particular, our study provides various strategies, identified by stakeholders, needed for SAF commercial-level production, distribution and usage.

6.3. Practical contribution

In this study, we revealed SAF development as a coupled system of several stakeholder groups, who in their own existence are a system, working toward a common goal of mitigating aviation sector climate change and ensuring fuel transition. Through our research each stakeholder group can identify and strategize its way that suits its own context on SAF development. This is possible by selecting a suitable enabler, option, or a combination of thereof. For example, producers could ensure business profitability and sustainability by approaching equity markets for debt financing, or airlines raise ticket price to minimise price differential, so on and so forth. Similarly, our study demonstrated a clear understanding of the constraints and concerns (e.g., refineries worry about losing their license; or having a global mandate is difficult) across all participating stakeholders critical to the success of SAF deployment. This knowledge can be leveraged by key decision-makers for designing relevant mitigating actions. Finally, our research contributed to the policy and
regulation domain by highlighting the impact of policy options (see Fig. 7). This understanding is vital for policymakers to see the ramifications of proposed policies as they sit in the wider SAF market development.

6.4. Future research

In terms of further research, questions concern how different mechanisms (e.g., carbon pricing), and how different mandates (production and usage), shape the SAF market development in an international context. Similarly, there are questions about how firms adjust their business strategy in response to different and possibly competing stakeholders. Furthermore, we echo Spanellis et al. (2020) and Kim et al. (2019) who advocate developing a cognitive map into a quantitative simulation model. We envisage that such a tool for the SAF system would provide a test bench to stakeholders to see the system responses to various strategies aiming at the transition to SAF use and achieving carbon–neutral growth for the aviation sector.

CRediT authorship contribution statement

Salman Ahmad: Methodology, Software, Formal analysis, Writing – original draft. Bing Xu: Conceptualization, Investigation, Project administration, Validation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trd.2021.103076.

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