Alternative jet fuels and the *business of freedom*: a socio-environmental perspective for mitigating the climate impact of aviation

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List of abbreviations and acronyms

AJF	Alternative jet fuels
ATAG	Air Transport Action Group
BC-LCFS	British Columbia's Low-Carbon Fuel Standard
CAEP	Committee on Aviation Environmental Protection
CAF	Conventional aviation fuels
CBSCI	Canada's Biojet Supply Chain Initiative
CFS	Clean Fuel Standard (Canada)
CI	Carbon intensity
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
EU ETS	European Union Emissions Trading Scheme
GARDN	Green Aviation Research and Development Network
GHG	Greenhouse gas
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICSA	International Coalition for Sustainable Aviation
LCAF	Lower carbon aviation fuels
LH_2	Liquid hydrogen
NDCs	Nationally Determined Contributions
NGO	Non-governmental organization
PCF	Pan-Canadian Framework on Clean Growth and Climate Change
PNS	Post-Normal Science
RF	Radiative forcing
RD&D	Research, development and demonstration
SAF	Sustainable Aviation Fuels
SAFI Canada	Pan-Canadian Sustainable Aviation Fuels Initiative
SARPs	Standards and Recommended Practices
SARS-CoV-2	Severe acute respiratory syndrome coronavirus 2 aka COVID-19
SDGs	Sustainable Development Goals
SPK	Synthetic paraffinic kerosene
UNFCCC	United Nations Framework Convention on Climate Change
WPR	What's the problem represented to be? (method)

Units

Gt	Gigatonne (billion tonnes)
Mt	Megatonne (million tonnes)
MLY	Million litres per year
Wh/kg	Watt-hour per kilogram

Conversion factors

1 kilogram of jet fuel consumed = 3.16 kilograms of carbon dioxide emissions
1 kilogram of jet fuel (s.g. 0.79) = 1.266 litres

Abstract

Reconciling the challenges of climate change and local pollution with those of economic growth and mobility, have become increasingly pressing and urgent. By 2050, carbon dioxide emissions from international and domestic aviation are anticipated to double their ~2.4% contribution to global warming; a figure that does not consider the radiative forcing effect of other emissions at cruise altitude.

Moreover, the redirected focus from climate action to the economic recovery and the restoration of air travel services brought forth by the SARS-CoV-2 pandemic, could amplify the rebound effect on these emissions in the absence of greater environmental ambition worldwide.

This doctoral dissertation investigated the role for alternative jet fuels (AJF) in mitigating the climate impacts of aviation in decades to come. This socio-environmental research was overarched by a Post-Normal Science (PNS) theoretical framework, where a mixed methodological approach to aeronautics and the application of out-of-field methods, were instrumental for the development of both the descriptive and the normative components of PNS.

The descriptive component of PNS centered on the implications for environmental governance, of defining post-normal issues in terms of what is and what can be known. Its normative component focused on identifying mechanisms for informing and improving decision-making in the air transport sector, based on reflexive, inclusive and transparent scientific inquiry.

The analysis of the discursive foundations of aviation climate policy, including the International Civil Aviation Organization's (ICAO) alternative jet fuel strategy, revealed abiding instances of data obliquity, information gaps and asymmetries underlying unquestioned forms of problem representations apropos the environmental impacts of air transport.

Some of the options identified in this thesis for addressing these issues encompass: a) an enhanced transparency and access to data collected by governments, industry, academia and other third-parties on aviation emissions from and beyond fuel combustion, b) the harmonization of epistemologies for measuring, allocating, assessing, verifying and reporting environmental data so

as to render it comparable, c) a reassessment of the sectoral approach to the Sustainable Development Goals (SDGs) for aligning aviation policies and actions with the aims of the UN 2030 Agenda for Sustainable Development, d) greater engagement of stakeholders in the qualitative production, appraisal and use of knowledge, and e) a broad outreach to end-users for getting them involved, individually, in climate action.

Problem (mis)representations within the aviation sector have historically bolstered a weak sustainability approach to its sectoral growth that, unless unsettled and replaced by strong sustainability narratives, will continue to effect long-term micro and macroscale risks and repercussions on people and the environment.

These discursive and non-discursive practices may also hinder future deployment of sustainable AJF – particularly in countries rich in fossil resources such as Canada – by encouraging the production of fossil-derived fuels, known as lower carbon aviation fuels (LCAF), and when more economical, by favoring carbon offsetting over direct emissions abatement.

Whilst the air transport industry has pledged to robust sustainability standards for upscaling global production of AJF, adherence solely to the ICAO's criteria for eligible fuels under its Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), entails considerable short and long-term social, environmental and economic ramifications.

Weak sustainability narratives in the aviation sector can be challenged by participatory decision-making, where the understanding of *what* matters, *why* does it and *who* says so is as relevant to the future of AJF as their economies of scale. Multi-stakeholder partnerships are promising mechanisms for bringing ofttimes overlooked strong sustainability perspectives and expertise, into the formulation of policies and regulations on AJF beyond the work of the ICAO.

To illustrate this, the Canadian case study offered a comprehensive overview of the status, obstacles, opportunities and next steps for strategically addressing commercialization barriers for AJF, by means of a national roadmap – SAFI Canada. This roadmap was the result of the active and pluralistic involvement of stakeholders within a community of interest on AJF that was partly gathered for this purpose.

The new geopolitical reality shaped by the SARS-CoV-2 pandemic, together with the profound transformation of the world's energy systems, places Canada in a unique juncture to regain leadership in the development and commercialization of AJF by leveraging on its diversified community of stakeholders, its natural resources, technological capabilities, collaborative experience on AJF projects and potentially, a propitious regulatory framework for including these fuels in federal and provincial legislations.

Résumé

La conciliation des défis découlant du changement climatique et de la pollution locale à ceux associés à la croissance économique et à la mobilité est devenue de plus en plus pressante et urgente. Les émissions de dioxyde de carbone que génèrent l'aviation internationale et le transport aérien intérieur, contribuant aujourd'hui à hauteur de 2,4 % de l'ensemble des émissions de CO_2, devraient doubler d'ici 2050. Ce chiffre ne tient toutefois pas compte de l'effet du forçage radiatif des autres émissions en altitude de croisière.

De plus, le recentrage des priorités sur la reprise économique et le rétablissement des services de transport aérien à l'issue de la pandémie de SRAS-CoV-2, au détriment de l'action climatique, pourrait amplifier l'effet de rebond sur ces émissions en l'absence d'une plus grande ambition environnementale dans le monde.

Cette thèse de doctorat étudie le rôle des carburants d'aviation durables (AJF) dans l'atténuation des effets du transport aérien sur le climat dans les décennies à venir. Cette recherche socio-environnementale s'inscrit dans un cadre théorique de science post-normale (PNS). Une approche méthodologique mixte appliquée à l'aéronautique et le recours à des méthodes hors domaine ont joué un rôle déterminant dans l'élaboration des composantes descriptive et normative prévues à la PNS.

La composante descriptive est centrée sur les implications, pour la gouvernance environnementale, de la définition des problèmes post-normaux en termes de ce qui est connu et de ce qui peut l'être. Sa composante normative vise l'identification de mécanismes d'information et d'amélioration de la prise de décisions dans le secteur du transport aérien sur la base d'une enquête scientifique réflexive, inclusive et transparente.

L'analyse des fondements discursifs de la politique climatique de l'aviation, dont ceux de la stratégie de l'Organisation de l'aviation civile internationale (OACI) pour les carburants d'aviation durables, a révélé des cas persistants d'obliquité des données, de lacunes dans l'information et d'asymétries sous-jacentes à des formes incontestées de représentations des problèmes concernant les répercussions environnementales du transport aérien.

Certaines des solutions expliquées dans la présente thèse pour résoudre ces problèmes comprennent : a) le renforcement de la transparence et de l'accès aux données collectées par les gouvernements, l'industrie, les universités et d'autres parties prenantes sur les émissions de l'aviation provenant notamment de la combustion de carburant; b) l'harmonisation des épistémologies pour mesurer, attribuer, évaluer, vérifier et rendre compte des données environnementales de manière à pouvoir établir des comparaisons; c) une réévaluation de l'approche sectorielle des objectifs de développement durable (ODD) en vue de favoriser l'adéquation des politiques et actions de l'aviation avec les objectifs du Programme des Nations Unies de développement durable à l'horizon 2030; d) un plus grand engagement des parties prenantes dans la production qualitative, l'évaluation et l'utilisation des connaissances; et e) une large sensibilisation des utilisateurs finaux pour mobiliser chacun d'eux dans l'action climatique.

Les (fausses) représentations des problèmes inhérents au secteur de l'aviation ont historiquement minimisé l'importance de la durabilité au regard de la croissance sectorielle. À défaut de remplacer ces représentations par des discours sur la 'durabilité forte', les répercussions de l'aviation sur les populations et l'environnement se feront sentir encore longtemps, à petite comme à grande échelle.

Les pratiques discursives et non discursives peuvent également entraver le déploiement futur des carburants d'aviation durables en particulier dans les pays riches en ressources fossiles comme le Canada, où la production de carburants aéronautiques à faible teneur en carbone (LCAF), associée à la compensation carbone, s'avère plus économique que la réduction directe des émissions.

L'industrie du transport aérien s'est engagée à mettre en œuvre des normes de durabilité robustes pour augmenter la production mondiale d'AJF. Or, l'adhésion aux seuls critères de l'OACI pour les carburants admissibles dans le cadre de son programme de compensation et de réduction des émissions de carbone pour l'aviation internationale (CORSIA) suppose des ramifications sociales, environnementales et économiques considérables à court et à long terme.

La faiblesse des discours sur la durabilité dans le secteur de l'aviation peut être contrée par la prise de décisions participative dans la mesure où sont compris le *quoi*, le *pourquoi* et le *qui*, lesquels s'avèrent tout aussi pertinents que les économies d'échelle pour l'avenir des AJF. Les partenariats multipartites sont des mécanismes prometteurs qui permettent d'intégrer des perspectives et une expertise sur la ‘durabilité forte’, ces dernières étant souvent négligées dans la rédaction de politiques et de réglementations sur les AJF au-delà du travail de l’OACI.

L’étude de cas canadienne est la parfaite illustration de ce qui précède. Elle dresse un portrait complet de la situation, des défis, des possibilités à saisir et des prochaines étapes de manière à franchir stratégiquement les obstacles à la commercialisation des AJF. C’est à partir de cette étude qu’a été élaborée une feuille de route nationale appelée SAFI Canada. Elle est le résultat de la participation active et pluraliste des parties prenantes au sein d’une communauté d’intérêts sur les AJF, en partie réunie à cet effet.

La nouvelle réalité géopolitique découlant de la pandémie de SRAS-CoV-2, sur laquelle se transpose la transformation profonde des systèmes énergétiques mondiaux, constitue un tremplin dont le Canada devrait se servir pour regagner son leadership dans le développement et la commercialisation des AJF. Il s’agira donc de tirer parti de sa communauté diversifiée de parties prenantes, de ses ressources naturelles, de ses capacités technologiques, de son expérience de collaboration sur les projets d’AJF et, potentiellement, d’un cadre réglementaire approprié intégrant ces carburants dans les lois fédérale et provinciales.

Select publications and collaborations

1. Soria Baledón, M., Assessing the discursive foundations for emissions abatement in aviation: a post-normal science primer on alternative jet fuels, *Ecological Economics*. [Manuscript submitted on March 24, 2021]

2. Soria Baledón M., Trudel M. and N. Kosoy (2021), Alternative jet fuels and climate geopolitics: *what*, *why* does it and *who* matters in the environmental policy-making process, *International Journal of Sustainable Transportation*. https://doi.org/10.1080/15568318.2021.1912225

3. Derkach K., Soria Baledón M., Avalle E. and M. Kacem (2019), Sustainable aviation fuels: a Canadian Perspective. Report prepared by GARDN for Environment and Climate Change Canada (ECCC), Montreal [Institutional Publication]. Available at: https://safcommunity.org/page/white-paper

4. Soria Baledón, M. (2018) Stakeholders mapping. Report prepared by GARDN for Natural Resources Canada's (NRCan) Impact Canada Initiative – Biojet Innovation Challenge "Innovating for a Green Aviation Fuel Future", Montreal [Institutional Publication]. Available at: https://safcommunity.org/page/stakeholders-map-resources

5. Soria Baledón, M. and N. Kosoy (2018), "Problematizing" carbon emissions from international aviation and the role of alternative jet fuels in meeting ICAO's aspirational goals, *Journal of Air Transport Management*, 71:130-137. https://doi.org/10.1016/j.jairtraman.2018.06.001

6. Soria Baledón, M. (2017), "Regulations for Oilseeds as Alternative Fuel Feedstocks", in BioFuelNet Canada, What role of advanced biofuels in Canada? A Q&A of policy impacts and options, pp.25-31. Available at: http://www.biofuelnet.ca/nce/wp-content/uploads/2013/02/Biofuel-QA-Report-KTF-Apr-6-Final.pdf

7. Soria Baledón, M. (2016, September 26), "Climate policy: the risk of diversion or a promise of change". [Blog post]. Available at: http://www.biofuelnet.ca/2016/09/26/climate-policy-risk-diversion-promise-change/

8. Soria Baledón, M. (2016, January 13), "Making possible the impossible: a globally sustainable aviation sector". [Blog post]. Available at: http://www.biofuelnet.ca/2016/01/13/making-possible-impossible-globally-sustainable-aviation-sector/

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Preface

The existence of alternative jet fuels came to my attention in 2014, while working as Director of Biofuels at the Ministry of Energy (SENER) in Mexico. At the time, I had professional experience with other liquid, solid and gaseous fuels and was aware of the deep complexities to promote the adoption of clean energy in a country so heavily dependent on its fossil resources.

Although I did not comprehend the extent of the environmental and climate impacts of aviation, I was fascinated by the outlook of taking my expertise one step further by actively engaging in the promotion of alternative jet fuels (AJF) in my home country. Only a decade ago, Mexico had pioneered the field and had demonstrated international leadership spearheaded by Capt. Gilberto López Meyer and Dr. Alejandro Ríos Galván at Aeropuertos and Servicios Auxiliares (ASA), and by Eng. Roberto Kobeh González, then president of the ICAO Council.

So, together with a former colleague from ASA, our teams had a very busy 2014 advocating and participating national and international stakeholders to advance research, development and commercialization of AJF. But other high-level political priorities averted our efforts from coming to fruition…

In 2015, the opportunity to pursue a doctoral degree in the subject fully funded by the now defunct BioFuelNet Canada, allowed me to learn from other countries' experiences but foremost, it made me aware of the formidable planetary challenge that I had ventured on. Beyond my professional passion for AJF, mitigating the impacts of aviation became a moral responsibility towards nature, present and future generations.

Far from the financial possibility (and desire!) of becoming a *jet setter*, I am still part of the privileged ~ 4% of the global population that in 2018 had ever taken a flight. And as Canadian citizen, my second home country happens to be amongst the top aviation emitters, even on a per capita basis, with up to 204 $tCO_{2}e$ per person per year in comparison to 0.1 $tCO_{2}e$ in some parts of Africa!

Reckoning on my life choices, I would not be the person that I am today without the self-development experiences facilitated by aviation, where another turning point already awaits me. Thereupon, it is with unfathomable gratitude, felicity and optimism that I close this profoundly transformative undertaking, to pursue new exploits and cleaner skies.

Vancouver, 2021

Acknowledgements

The completion of this academic endeavor, at times treacherous, disempowering and never short of tribulations, would not have been possible without the unconditional kindness, generosity, compassion and love of my parents and all the beautiful people – friends, family, colleagues, professors, the occasional altruist and the good Samaritans – to whom I am forever indebted with boundless gratitude.

From almost all continents in the planet (I have not yet befriended a resident of Antarctica), empathy always made its way to the tiny studio on Avenue du Parc where I spent most of my student days. In good times and difficult ones, in health and illness, in abundance and scarcity, in trust and deception, in celebration and grievance, in joy and sadness, and in love and heartbreak, I was never let down.

And in the aftermath of the earthquake that struck several Mexican states in September of 2017, including Mexico City, that kindness, generosity, compassion and love were also bestowed upon my family, who were able to provide immediate relief to neighbours, relatives and strangers alike.

Nine years after immigrating solo to Canada, I came full circle to the home and the *room of my own* that have – ever since – embarked me into new beginnings. After all, COVID-19 had a silver lining: to be reunited with a growing family – all of us immigrants from different parts of the world – kindred by dreams, aspirations, love and friendship.

Thank you all.

A mis abuelos,
Yolanda Irene Sánchez Amaya y Guillermo René Soria Esparza,
en honor a nuestro pacto de amor

"Thought […] offends or reconciles, attracts or repels, breaks, dissociates, unites or reunites; it cannot help but liberate and enslave. Even before prescribing, suggesting a future, saying what must be done, even before exhorting or merely sounding an alarm, thought, at the level of its existence, in its very dawning, is in itself an action – a perilous act."

Michel Foucault, 1977

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Authorship and contributorship

The author was solely responsible for the conceptual design, planning, execution and revision of this thesis and of the publications derived thereof in partial fulfillment of the academic requirements for the degree of Doctor in Philosophy. Prof. Nicolás Kosoy supervised this thesis, contributed to the methodological design of chapters 3 and 4 and advised the author with appropriate and timely feedback throughout the entire research process.

For chapter 4, Dr. Marcel Trudel provided general guidance on the application of Q-method, he assisted the author with the processing and analysis of raw data using IBM SPSS Statistics, and contributed with critical feedback to the manuscript submitted for publication.

Chapters 5 and 6 were originally written by the author of this thesis while employed at the Green Aviation Research and Development Network (GARDN) between 2017 and 2019. Chapter 5 extracted and expanded the regulatory and policy analysis conducted as part of an institutional report[1] commissioned by Environment and Climate Change Canada (ECCC) and published by GARDN in 2019 on the status of AJF nationally.

Several sections of that report were co-authored with Kateryna Derkach, Elvire Avalle and Malek Kacem, who collectively contributed to the design, data collection, analysis and writing of the final deliverable.

Full authorship of chapter 5 as presented in this doctoral research corresponds to Mónica Soria Baledón, excepting the conceptual design of SAFI Canada, its visuals and the set of policy recommendations included in section 5.5 (The Pan-Canadian Sustainable Aviation Fuels Initiative – SAFI Canada).

[1] Derkach K., Soria Baledón M., Avalle E. and M. Kacem (2019), Sustainable aviation fuels: a Canadian Perspective. Report prepared by GARDN for Environment and Climate Change Canada (ECCC), Montreal. Available at: https://safcommunity.org/page/white-paper.

Whilst chapter 6 was also written by the author in her quality of employee at GARDN, there were no other contributing authors to the document originally published[2] in 2018 nor to the chapter herein.

Data for chapter 4 were collected independently as a student at McGill University while data for chapters 5 and 6 were collected as an employee at GARDN. This distinction is relevant insofar the institutional approvals, informed consent forms, collection protocols and participants' personal information used in chapter 4 are archived with the author of this thesis[3], while those used in chapters 5 and 6 are stored within GARDN's archives, to which the author no longer has access.

[2] Soria Baledón, Mónica (2018) Stakeholders mapping. Report prepared by GARDN for Natural Resources Canada's (NRCan) Impact Canada Initiative – Biojet Innovation Challenge "Innovating for a Green Aviation Fuel Future", Montreal. Available at: https://safcommunity.org/page/stakeholders-map-resources

[3] Documentation and approvals by the FAES Research Ethics Board Office of McGill University (REB file no.175-0917) are annexed to this thesis (Annex).

What novelty? A theoretical and methodological proposal

Most of the white and grey literature published in the last 20 years has focused on the chemistry of alternative jet fuels – still commonly referred to as biofuels, on the techno-economic analysis of conversion processes, on the characterization of biogenic feedstocks suitable for upscaling production, and more recently, on the environmental sustainability of alternative fuels and their policy and regulatory frameworks worldwide.

However, the academic literature on the social aspects of AJF is scarce and, to the best knowledge of the author, the methods used in this doctoral dissertation – individually and combined – are entirely novel to the field. This observation is not minor, as the methodological proposal presented throughout this thesis was advantageous for approaching and reframing intractable and highly sensitive and/or politicized aspects of the AJF debate, while making them more amenable for analysis, deliberation and decision-making.

The theoretical framework overarching this research is Post-Normal Science (PNS). Emerging from the field of ecological economics, post-normal science was developed in the early 1990s by Silvio Funtowicz and Jerome Ravetz to study environmental issues of irreducible complexity, deep uncertainties, a plurality of legitimate perspectives, high stakes, value dissent and urgency of decision-making (Funtowicz and Ravetz 1993).

PNS is both descriptive (i.e. how does the definition of post-normal issues affect environmental governance, based on what is and can be known?) and normative (i.e. how to inform and improve policy-making, based on reflexive, inclusive and transparent scientific inquiry?) (Strand 2017). Detailed in chapter 1, the descriptive component of PNS is developed in chapters 2 and 3, and its normative component in chapters 5 and 6. Chapter 4 is both descriptive and normative in its approach to AJF.

Despite its ontological and epistemological flexibility for approaching global environmental challenges, the existing body of research using PNS is highly heterogeneous in terms of conceptualizations, methods, best practices and applications (Turnpenny et al. 2011). For this reason, this doctoral research uses a mixed methodological approach and applies out-of-field methods to investigate the role for alternative jet fuels in mitigating the climate impact of aviation.

Mixing methods offered the author a unique opportunity to critically interrogate unquestioned forms of scientific inquiry (Latour 1987), for unsettling assumptions about what can be known, and how knowledge is and should be produced (Sneegas 2019; Elwood 2009). Furthermore, this methodological pluralism made it possible to transcend the “either/or” divides in favor of “both/and” approaches, by reflexively and responsibly engaging ostensibly divergent ontologies and epistemologies into dialectic harmony.

1

An atypical approach to aviation fuels

(Introduction)

The aviation sector as we know it today is merely a century old, but the convenience and reliability of air travel on which modern society and the global economy became so deeply dependent, also turned it into the fastest growing sector compared to any other forms of transport (IATA 2015).

In 2019, the aviation sector contributed with 4.1% of the global gross domestic product (GDP), supported 87.7 million direct, indirect, induced and catalytic jobs, and transported 4.5 billion passengers (ATAG 2020a).

Conversely, air travel currently accounts for ~2.4% of the total carbon dioxide (CO_2) emissions from anthropogenic origin (Lee et al. 2021), a contribution that could double when the radiative forcing effect of non-CO_2 emissions at cruise altitude is accounted for (Lee et al. 2021; Grewe 2020; Moore et al. 2017; Novelli 2011; Lee et al. 2009; Penner et al. 1999; Brasseur et al. 1998).

In 2020, the global outbreak of the SARS-CoV-2, hereafter referred to as COVID-19, led to a near shutdown of the air transport sector worldwide (ATAG 2020a; Pearce 2020), entailing a net financial loss of approximately USD 118.5 billion (IATA 2020b). Whereas the air traffic forecasts out to 2050 are conservative, global demand is projected to recover to pre-pandemic levels by 2024, equivalent to an annual sectoral growth of 4.1% with an associated 2.9% annual increase in emissions (ATAG 2020a; WBG 2020; Pearce 2020).

Albeit seemingly small, the air transport sector's contribution to climate change in 2019 amounted to 918 $MtCO_2$ (Graver et al. 2020); a figure well above the total emissions of Germany (695 $MtCO_2$) and closer to those of Japan (1.16 $GtCO_2$) – ranked as the fifth largest emitter in 2018 (IEA 2020; UCS 2020). In a post-pandemic scenario, emissions from international and domestic aviation are expected to reach 1.82 $GtCO_2$ by 2050[1]; nearly double of those from all commercial operations[2] in 2018 and greater than the total emissions of the Russian Federation (1.71 $GtCO_2$) for the same year (IEA 2020; UCS 2020; ICAO 2019).

Though national and international efforts to reduce the environmental impacts of aviation can be traced back as early as the 1980s, it was not until the last decade that reconciling the challenges of climate change and local pollution with those of economic growth and mobility have become increasingly pressing and urgent.

In the context of the Paris Agreement, the climate commitments undertaken by the air transport industry in 2009, as well as those agreed upon by the UN International Civil Aviation Organization[3] (ICAO) throughout the last 10 years, do not appropriately account for the required carbon reductions to limit global warming well below 2°C (WEF 2020a; Fichert et al. 2020; Masson-Delmotte et al. 2018; Soria Baledón and Kosoy 2018; Pidcock and Yeo 2016).

Whilst the attainment of these commitments has encompassed improvements in operations, technologies, the use of alternative jet fuels (AJF) and the creation of a global offsetting scheme to indirectly mitigate emissions from international aviation's growth between 2021 and 2035; the overall sectoral emissions are anticipated to outpace the reductions in the absence of greater climate ambition and strategy.

In light of the intensifying pressure on the air transport sector to address its environmental impacts, the use of alternative jet fuels (AJF) has been increasingly perceived by governments and by the industry alike (WEF 2020a; ATAG 2020b; IATA 2020a; ICAO 2019; de Jong 2018; Staples et al. 2018; DOE 2017) to hold the greatest potential to enable and accelerate the sectoral transition towards carbon-neutrality by 2060/2065 (ATAG 2020a) for several reasons.

[1] This estimate does not consider the RF effect of non-CO_2 emissions at cruise altitude.
[2] International aviation is responsible for 61-65% of the global sectoral share of emissions (Graver et al. 2020; ICAO 2016).
[3] The ICAO is the United Nations specialized agency responsible for the development of standards, recommended practices and guidance to guarantee the safe, regular, efficient, economical and sustainable development of civil aviation internationally.

Firstly, the current technological barriers to power aircraft with cleaner energy carriers (e.g. electrical and hybrid-electric propulsion, hydrogen fuel cells) make the air transport reliant exclusively on liquid fuels. Alternative jet fuels (AJF) refer to the variety of drop-in substitutes[4] for petroleum-based fuels or conventional aviation fuels (CAF) that satisfy jet fuel form, fit, safety and performance requirements[5].

AJF are produced from biogenic feedstock sources (e.g. agronomic and lignocellulosic crops, algae, agricultural and forestry residues, residue lipids, biogenic fraction of municipal solid waste, biogas, CO_2 from direct air capture) via thermochemical and biochemical routes (Bauen et al. 2020). AJF from non-biogenic feedstock sources (e.g. industrial off-gases, unconventional petroleum) are known as lower carbon aviation fuels (LCAF).

Secondly, even if a technological breakthrough would become commercially available before 2050, innovations and developments in the aviation sector usually take up to a couple of decades before reaching maturity (IATA, 2013). Thirdly, fleet turnover is slow since aircraft remain in service for 25 years on average and can only be phased-out gradually (Jiang 2013).

Alternative jet fuels were approved for use in commercial aviation in 2009 (ASTM D7566-09), followed by a number of test flights and trials by airlines to promote their uptake. Since 2011, over 320,000 flights[6] have used AJF and production capacity is forecast to reach 2.7 Mt (3.5 bn litres) per year by 2025, equivalent to 7 $MtCO_2$ avoided[7] (ATAG 2020b; Boyd 2019).

Emissions from aviation are based on fuel consumption[8], which has been anticipated to grow from 142 Mt (180 bn litres) of jet fuel in 2010, to 450-570 Mt (570-720 bn litres) in 2050 (ATAG 2020b;

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[4] Meaning that they do not require modifications to existing jet engines nor to the fuel supply infrastructure.

[5] The international aviation community uses the term sustainable aviation fuels (SAF) to refer to drop-in alternative fuels that meet verifiable sustainability standards. However, in the absence of a global standard that comprehensively addresses environmental protection from a strong sustainability perspective (Ayres et al. 2001; Gowdy 2000; Goodland 1995), the author considered the proposed term (AJF) to better represent the variety of drop-in substitutes for CAF.

[6] https://aviationbenefits.org/environmental-efficiency/climate-action/sustainable-aviation-fuel on March 25, 2021.

[7] Assuming an 80% CO_2 reduction potential on a lifecycle basis (ATAG 2020b).

[8] Fuel burn forecasting relies on aviation traffic modelling, data of baseline fleet, technology and operational improvements.

CAAF/2-WP/06). Presently, commercial volumes of alternative jet fuels remain limited and mostly supplied through off-take agreements between airlines and fuel producers (Boyd 2019).

Among other factors, the shortfalls in global production of AJF over the past decade have been mainly attributed to: 1) the lack of dedicated policies and harmonized regulations to stimulate market development, and 2) to the limited availability of verifiable sustainable feedstocks for satisfying the global fuel demand using commercially mature technologies (WEF 2020b; ATAG 2020b; ICAO 2019; Deane and Pye 2018; Bosch et al. 2017).

In 2018, approximately 14 million litres (0.01 Mt) of AJF were blended with conventional aviation fuel (ATAG 2018) and in 2019, this figure nearly trebled to 40 million (0.03 Mt) AJF, yet accounting for <0.01% of the global aviation fuel demand for the same year (ATAG 2020c; IATA 2020a).

By 2025, AJF are expected to reach a tipping point in the supply/price balance at 2% of the global aviation fuel stock (ATAG 2020d); however, meeting the Paris Agreement goals will likely require almost full replacement of conventional jet fuels (CAF) and lower carbon aviation fuels (LCAF) by AJF capable of lifecycle emissions reductions of at least 80% (WEF 2020b; ATAG 2020b; ICAO 2019).

With this as point of departure, this doctoral dissertation discusses – from a socio-environmental perspective – the role of alternative jet fuels in enabling the air transport sector to attain its global climate targets out to 2050 and beyond.

1.2. Problem representations, research questions and objectives

The nature, scope and type of solutions articulated through public policy, together with their material and symbolic impacts on people and the environment, inexorably derive from specific forms of “problematizations” (Foucault 1988); also known as problem representations in public policy analysis (Bacchi 2009).

Thereupon, this research critically interrogates the problem representations articulated apropos the environmental impacts of aviation based on the following questions:

1. How have emissions from the air transport sector been discursively constructed and articulated as a global issue?
2. What are the premises and effects of the problem representations underlying ICAO's – and more broadly the industry's – alternative jet fuel strategies?
3. How can the dominant premises and problem representations be disrupted so as to constructively and inclusively inform policies on AJF within and beyond national jurisdictions?

These questions underpin the objectives of this research to: 1) improve our understanding of the environmental impacts of aviation beyond its ~2.4% global CO_2 contribution, 2) reassess the status, challenges and opportunities for AJF for closing the carbon loop of the air transport sector, 3) examine the role and influence of stakeholder perceptions in shaping policies and regulations that are supportive of AJF deployment, and 4) inform policy-making on AJF, using Canada as case study, by actively and pluralistically engaging stakeholders in the qualitative production, appraisal and use of knowledge.

Canada was selected as case study for several reasons. First, because emissions from its aviation sector (both domestic and international) are higher than the global average due to the role of air transport in supporting trade and connectivity through its large landmass; particularly to remote communities that can only be accessed by air (Graver et al. 2020; Gössling and Humpe 2020; TC 2018). Furthermore, the demand for air transport services has grown steadily and, despite the annual fuel efficiency gains from enhanced technologies, operations and navigation, the total sectoral emissions have also increased (TC 2019).

Second, Canada was among the first countries to voluntarily set environmental targets to abate emissions from aviation, and to pioneer collaborative research into the development of alternative jet fuels (TC 2012). Third, ongoing efforts to reduce sectoral CO_2 emissions encompass a variety of federal and provincial regulatory and policy instruments that, if addressed comprehensively, could stimulate the development of a Canadian AJF industry and contribute to the attainment of Canada's climate goals under the Paris Agreement (ECCC 2020; Derkach et al. 2019).

Last but not least, Canada has abundant biogenic feedstock sources from its agricultural and forestry sectors for long-term production of AJF (CBSCI 2019; van Dyk et al. 2019), and it has the technologies and a developing infrastructure with the potential for upscaling AJF conversion pathways with high sustainability profiles. However, Canada also has plentiful non-biogenic feedstock sources for producing lower carbon aviation fuels (LCAF) (BP 2020; Hileman et al. 2009), which risks a continued domestic dependence on fossil-derived jet fuels.

1.3. General structure and methods

This introductory chapter – chapter 1 – is followed by seven others. The second chapter introduces post-normal science (PNS) as a theoretical framework to critically and reflexively review the discursive foundations of environmental policy in aviation, as well as for reassessing the status, challenges and opportunities for AJF to close the carbon loop of this hard-to-abate sector. Whereas chapter 2 discusses some of the techno-economic elements relevant to the advancement and upscaling of AJF, it relies on Michel Foucault's thinking "problematically" method of analysis, to identify and understand common problem (mis)representations affecting policy-making internationally.

Chapter 3 utilizes Carol Bacchi's *what's the problem represented to be?* (WPR) method of discourse analysis, with the main objective to identify and gain a better understanding of the premises and effects, both symbolic and material, of the problem representations constructed and articulated by the air transport sector concerning its climate impact. The analysis centers on the ICAO's alternative jet fuel strategy; with a secondary objective of challenging the dominant representations in favor of those articulated from a strong sustainability perspective.

The WPR is a six-step method of public policy analysis that follows a set of questions: [Q1] What is the "problem" represented to be in a given policy? [Q2] What assumptions underlie this problem representation? [Q3] How has this representation of the problem come to prominence? [Q4] What does this representation of the problem take for granted and leave unquestioned? [Q5] What effects are produced by this representation? [Q6] How and where is this representation of the problem produced, disseminated and defended? And how could it be challenged?

Building on the findings of the WPR, the fourth chapter combines qualitative and mixed methods to study stakeholder perceptions by identifying and analyzing collective narratives on AJF that have influence on the environmental policy process at the ICAO. Stakeholder viewpoints have been progressively acknowledged in socio-environmental research as the base for understanding *what* matters, *why* does it and *who* says so in decision-making processes, and as paramount to inform and improve environmental governance.

Chapter 4 primarily relies on Stephenson's Q-method to analyze subjectivity along the environmental, political, economic, technological and social dimensions of alternative jet fuels. Q-method is a mixed quantitative-qualitative tool to empirically investigate social perspectives on issues that directly affect policy-making. The methodological framework proposed in chapter 4 involves the combined application of Q-method with two other qualitative tools (i.e. participant observation and Mitchell's et al. stakeholder salience and classification) to add robustness to the overall analysis conducted by the author over the course of four years (2016-2019).

By classifying stakeholders' salience based on their possession of power, legitimacy and urgency as dynamic and relational attributes to the ICAO, this chapter suggests options to bring valuable expertise from low-salient and non-stakeholders into the formulation of policies on AJF. In addition to the extended discussion presented in chapter 7, chapter 4 explores the role for AJF in the context of the COVID-19 outbreak, the *flygskam* movement in Europe, and the impending renewal of climate commitments under the Paris Agreement.

The fifth and sixth chapters of this doctoral dissertation focus on the role for AJF in the Canadian context. Both chapters were originally written and published while employed at GARDN; a non-for-profit organization funded by the Business-Led Network of Centres of Excellence (BL-NCE) of the Government of Canada and the Canadian aerospace industry.

Chapters 5 and 6 compile and present an updated version of the research conducted between 2017-2019, to develop the Pan-Canadian Sustainable Aviation Fuels Initiative (SAFI Canada); a national AJF roadmap that builds on the decade-long experience of the Canadian aerospace sector in actively engaging its stakeholders into collaborative projects and initiatives. Chapter 5 discusses the accomplishments, the ongoing efforts and the gaps concerning the development of AJF in Canada by focusing on current and proposed policies and regulations.

Based on the findings of this analysis, as well as on the data collected through surveys, external consultations and personal communications, this chapter proposes a set of recommendations to operationalize the objectives of SAFI Canada along its six strategic areas: (1) research, development and demonstration (RD&D) and innovation, (2) financing and strategic partnerships, (3) policy and regulations, (4) technical and sustainability certifications, (5) outreach and knowledge transfer, and (6) consortia-building and regional initiatives.

In recognition of the key role of multi-stakeholder initiatives to support and accelerate the development of domestic supply chains of AJF in Canada, the sixth chapter concentrates on identifying and mapping the universe of stakeholders across provincial jurisdictions. A database and an interactive map were created by the author with the double purpose of: 1) assisting Natural Resources Canada's (NRCan) on the design of The Sky's the Limit Challenge[9], and 2) broadening GARDN's network by gathering and engaging a community of interest on Canadian AJF production.

Chapter 7 compiles and jointly discusses the findings presented throughout this thesis in the context of the COVID-19 pandemic but foremost, in achieving the aviation sector's climate goals in times of greater climate ambition and a new global reality. The general conclusions conform the eight and last chapter of this doctoral dissertation, where its limitations are explained as well as the areas within the field of alternative jet fuels where further socio-environmental research is needed.

[9] Launched in 2018 as part of NRCan's Impact Canada Initiative, the Challenge aims at developing and upscaling innovative, sustainable and competitive AJF production in Canada.

Foreword to chapter 2

The second chapter consists of a literature review. It introduces post-normal science (PNS) as the theoretical framework of this doctoral dissertation to critically and reflexively analyze the discursive foundations of environmental policy in aviation, as well as for reassessing the status, challenges and opportunities for AJF to close the carbon loop of the air transport sector.

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2

Assessing the discursive foundations for emissions abatement in aviation: a post-normal science primer on alternative jet fuels

(Literature review)

Abstract

Post-normal science was used to critically review the discursive foundations of environmental policy in aviation, and for reassessing the status, challenges and opportunities for alternative jet fuels to close the carbon loop of this hard-to-abate sector. The analysis revealed instances where data misrepresentation, information gaps and asymmetries, have precluded a comprehensive understanding of the environmental impacts of aviation beyond its ~2.4% global CO_2 contribution. Problem representations embedded in sustainability policies and regulations, have historically understated the urgency to implement ambitious climate strategies worldwide for addressing these impacts. For example, the current design of the sustainability standard for abating emissions from international aviation through the use of eligible fuels, entails significant short to long-term risks. These include: a) higher carbon debts, ecosystem damage and welfare loss from unsustainable fuel production, b) distortion of long-term market signal for alternative jet fuels with high sustainability profiles, c) constraints on investment and innovation for next-generation clean-fuel technologies, d) increased sectoral reputational risk and, foremost, e) a continued dependence on fossil-derived fuels. Looking out to 2050, problem (mis)representations can forestall global deployment of alternative jet fuels as much as they can avert setting more appropriate, realistic and fair environmental commitments for a new geopolitical reality.

Keywords: alternative jet fuels, post-normal science, policy problem representations, sustainable aviation, CORSIA, lower carbon aviation fuels.

Highlights

- Problem misrepresentations could forestall global deployment of alternative jet fuels
- Misrepresentations have bolstered a “psychology of denial” in air transport end-users

- Alternative propulsion architectures are unprovable to commercialize before 2040
- Lower carbon aviation fuels are not anticipated to displace fossil-derived fuels
- These fuels are incompatible with international decarbonization targets out to 2050

2.1. Aircraft propulsion and climate change

At the end of World War II, gas turbines rapidly replaced piston engines to increase aircraft speed, altitude and range in military and civil operations (Peeters et al. 2005). The technological transition entailed the substitution of aviation gasoline for kerosene to power jet engines, where petroleum-based fuels, hereafter referred to as conventional aviation fuels (CAF), have remained the primary energy carriers of the air transport sector since the 1950s[1] (González 1989).

Whilst CAF early development was somewhat dissimilar in the United States and in Europe, jet engine requirements evolved symbiotically to fuel specifications with differences of minor nature among national standards issued to date[2] (Rhode 2010).

CAF are middle distillates of crude oil refining[3] comprised of a mixture of aliphatic and aromatic hydrocarbon molecules in the C_7 to C_{18} range, where a typical distribution of these molecules consists of 30% mono-cycloparaffins, 25% n-paraffins, 16% mono-nuclear aromatics, 12% di-cycloparaffins, 11% iso-paraffins, 5% di-nuclear aromatics and 1% tri-cycloparaffins (Csonka 2015; Schobert 2013). The mixture of these molecules gives these highly refined types of kerosene the functional characteristics to perform as coolants, lubricants, hydraulic fluids, ballast fluids, swelling agents, capacitance agents, and as energy sources[4] (Rhode 2010; Strauss 2003).

Emissions from CAF combustion consist of carbon dioxide (CO_2), water vapour (H_2O), nitrogen oxides (NO_x), sulphur oxides (SO_x), carbon monoxide (CO), soot (PM 2.5), unburned hydrocarbons (HC), aerosols, traces of hydroxyl compounds (-OH), nitrogen (N_2) and oxygen (O_2), most of which are released in the atmosphere at cruise altitudes of 8-13 km above mean sea level (Lee et al. 2021; Grewe 2020; Moore et al. 2017; Novelli 2011; Lee et al. 2009; Penner et al. 1999; Brasseur et al. 1998).

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[1] ASTM D1655 *Standard Specification for Aviation Turbine Fuels* was issued in 1959 to define the properties, specifications, performance characteristics, test and sampling methods, etc., of petroleum-based aviation fuel for civil use (Jet A and Jet A-1).

[2] Rhode (2010) offers a detailed comparison of military and civilian requirements and grades for several CAF national specifications.

[3] Kerosene accounts for approximately 10% of the petroleum refining output (Schobert 2013; Creek 1989).

[4] Additives to improve CAF performance are usually added in very small amounts, such as antioxidants, lubricity enhancers, icing and corrosion inhibitors, etcetera.

Aviation's contribution to global warming is measured by the net radiative forcing[5] (RF as units of watts per square metre Wm^{-2}) resulting from changes in the physicochemical properties of the atmosphere, thereby impacting the radiation budget of the earth's climate system (Grewe 2020; Lee et al. 2009; Penner et al. 1999; Brasseur et al. 1998). The formation of contrail cirrus, the aviation-induced cloudiness (AIC) and the chemical reactions driven by NO_x emissions, collectively account for the largest warming forcing adding to that of CO_2, yet the scientific understanding of the non-CO_2 effects on atmospheric chemistry remains incomplete and somewhat contested (Lee et al. 2021).

Presently, air transport accounts for ~2.4% of the total CO_2 emissions from anthropogenic origin (Lee et al. 2021), but its net RF contribution to climate change is estimated between 3.5% and 4.9% whether the effect of AIC is accounted for or not (Grewe 2020; Moore et al. 2017; Novelli 2011; Lee et al. 2009).

Despite seemingly small, aviation emissions amounted to 918 $MtCO_2$ in 2019 (Graver et al. 2020), a figure well above the total emissions of Germany (695 $MtCO_2$) and closer to those of Japan (1.16 $GtCO_2$) – ranked as the fifth largest emitter in 2018 (IEA 2020a; UCS 2020). Forecasts out to 2050 anticipate emissions from international and domestic aviation to reach 1.82 $GtCO_2$[6]; nearly double of those from all commercial operations[7] in 2018 and greater than the total emissions of the Russian Federation (1.71 $GtCO_2$) for the same year (IEA 2020a; UCS 2020; ICAO 2019a).

Several conversion pathways for alternative jet fuels (AJF) show great potential for lifecycle emissions abatement (70%-100%) and production volumes could, in principle, supply the global fleet for commercial operations by mid-century (ATAG 2020a; WEF 2020). But the rapidly accrued geopolitical interest on AJF over the past decade to address the climate impact of aviation, together with the development and diversification of AJF conversion technologies, have not materialized into sufficient volumes to meaningfully displace CAF.

[5] Net warming is expressed by positive values of radiative forcing, while negative values express a net cooling effect (Penner et al. 1999).
[6] This estimate does not consider the RF effect of non-CO_2 emissions at cruise altitude.
[7] International aviation is responsible for 61-65% of the global sectoral share of emissions (Graver et al. 2020; ICAO 2016a).

Thereupon, the objective of this study is twofold: first, to critically and reflexively review the discursive foundations of environmental policy in aviation and, second, to reassess – from a social science perspective – the status, challenges and opportunities for AJF to close the carbon loop of this hard-to-abate sector[8]. Despite the noteworthy contributions of previous reviews on AJF from other disciplines that are referenced herein, this study approaches AJF using Post-Normal Science (PNS); a theoretical framework for investigating highly complex, uncertain, contested and time-sensitive issues (Funtowicz and Ravetz 1993).

Notwithstanding this review touches upon several techno-economic and sustainability aspects of AJF and other propulsion alternatives, it relies on Michel Foucault's thinking "problematically" method of analysis, to identify and understand the repercussions of specific forms of problem representations concerning the environmental impacts of aviation's growth – whether under unquestioned forms of scientific knowledge, political narratives, beliefs, etc. – in the nature, scope and type of solutions articulated through policies and regulations internationally.

2.2. Theoretical underpinnings for complex and uncertain "problematizations"

Post-normal science (PNS) was developed in the early 1990s by Silvio Funtowicz and Jerome Ravetz to study environmental issues of irreducible complexity, deep uncertainties, a plurality of legitimate perspectives, high stakes, value dissent and urgency of decision-making (Funtowicz and Ravetz 2003, 1994, 1993).

PNS originally emerged within the field of ecological economics (EE) as a criticism to the reductionism, oversimplification and technocratic traits and biases of evidence-based policies modelled in a "normal" or paradigmatic science tradition as defined by Kuhn[9] (Turnpenny et al. 2011; Funtowicz and Ravetz 1994; Ravetz 1971; Kuhn 1962).

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[8] Other hard-to-abate sectors include shipping, heavy road transport, steel, plastic and cement production (Victor et al. 2019).

[9] That is, scientific research based upon a set of beliefs, theories and methodologies – known as paradigms – that emerge out of consensus on exemplars within a research domain. In this tradition, normal science attempts to force nature into the puzzle-solving rules supplied by paradigms (Kuhn, 1962).

The theoretical framework proposed by PNS is both descriptive (i.e. how does the definition of post-normal issues affect environmental governance, based on what is and can be known?) and normative (i.e. how to inform and improve policy-making, based on reflexive, inclusive and transparent scientific inquiry?) (Strand 2017); where the active and pluralistic engagement of stakeholders – conceptualized as extended peer-communities by Funtowicz and Ravetz (1993) – is essential for the qualitative production, appraisal and use of knowledge (Dankel et al. 2017). The scope of this review is centered on the descriptive component of the PNS framework.

In the past 30 years, climate change has often been analyzed from a PNS perspective (Haikola et al. 2019; van der Sluijs 2012; Etkin and Ho 2007; Bray and von Storch 1999), and even though transport policies have been increasingly incorporating environmental considerations over and above concerns over inter- and intragenerational equity and justice (Funtowicz and Ravetz 2003), there are presently no studies on the environmental impacts of air transport using a PNS approach.

Since the 1960s, most of the research to address the environmental impacts of aviation has focused on its contributions to global warming, local air pollution, noise and, to a minor extent, on water contamination, ecosystems damage and biodiversity loss from airport and fuel infrastructure expansion (Bridger 2013; Kolmes 2011). While some of these concerns have been somewhat addressed through remediation programs and the development of technical Standards and Recommended Practices (SARPs) by the International Civil Aviation Organization[10] (ICAO), current limitations to the scientific understanding of the air transport's impact on climate change has hindered – to an extent – meaningful action through public policy.

To illustrate this point, the following figure (Fig. 2.1) taken from Lee et al. (2009) depicts – in a clear and simplified way – the direct and indirect impacts that aircraft emissions have, via climate change, on people and the environment[11].

[10] The ICAO is the United Nations specialized agency responsible for the development of standards, recommended practices and guidance to guarantee the safe, regular, efficient, economical and sustainable development of civil aviation internationally. SARPs for environmental protection comprise four volumes: Vol. I-Aircraft noise (1971), Vol. II-Aircraft engine emissions (1981), Vol. III-Aeroplane CO_2 emissions (2017), and Vol. IV-Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) (2018).

[11] In 2021, Lee et al. published a comprehensive update of their 2009 research for evaluating the anthropogenic climate forcing effect of aviation. However, the scope of their schematic overview was narrowed to the atmospheric processes affecting the climate system, leaving out the wider impacts of aviation on the human and natural ecosystems.

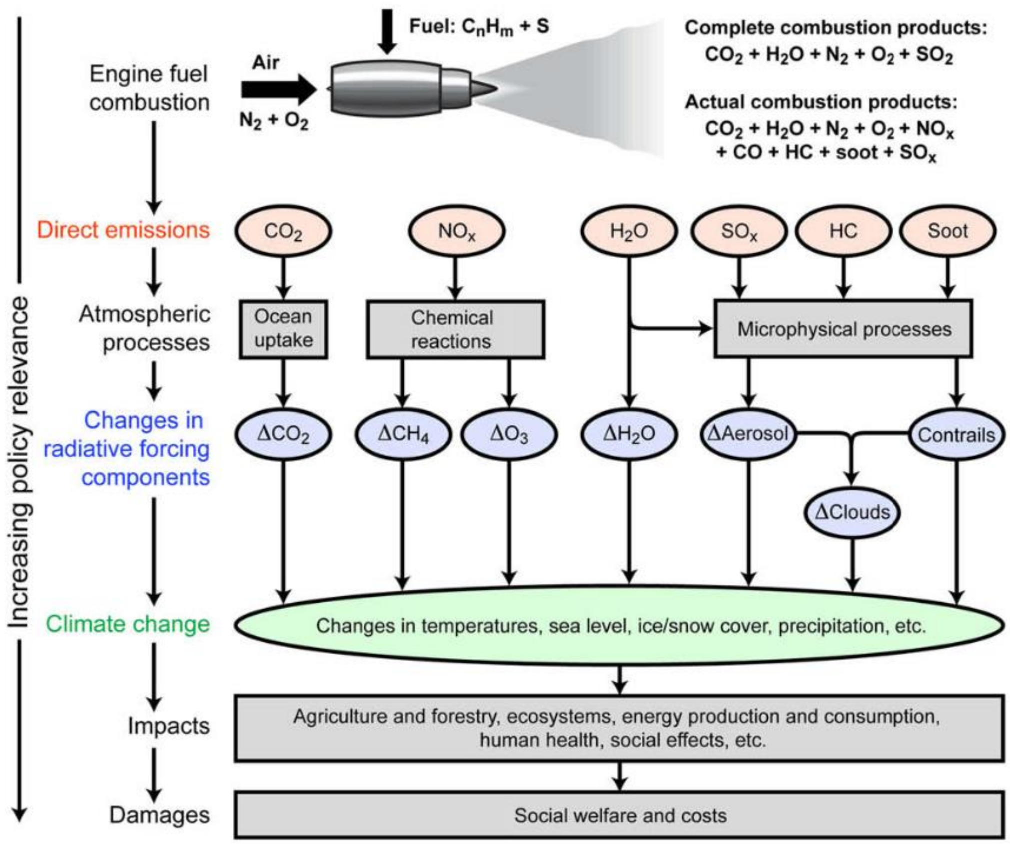

Figure 2.1. Aviation emissions and climate change (Lee et al. 2009)

A closer look on Figure 2.1 also reveals the incompleteness, uncertainty and complexity of the interactions between the human and the climate systems. Since Lee et al. (2009) do not attach any quantifiable values to their system representation, the urgency of decision-making, the plurality of legitimate perspectives, the value dissent and the high stakes of aviation's growth can only emerge as emissions are quantified and allocated.

This observation is not minor, as that the nature, scope and type of solutions articulated through public policy, as well as the material and symbolic impacts on the natural and human capitals resulting thereof, inexorably derive from specific forms of "problematizations" (Bacchi 2009).

Foucault defined "problematizations", also known as problem representations in public policy analysis (Bacchi 2009), as the discursive and non-discursive practices that constitute objects for thought whether under unquestioned forms of scientific knowledge, political analysis, moral reflection, etcetera (Foucault 1988). Hence, thinking "problematically" – this chapter's method of analysis – allows to critically and reflexively analyze problem representations discursively enshrined as truths and embedded in public policies, by understanding the historical process, the particular circumstances and the relations on which those problem representations rest upon (Bacchi 2012; Foucault 1977).

2.2.1. Thinking "problematically" about aviation growth

In 2020, the global outbreak of the SARS-CoV-2[12], hereafter referred to as COVID-19, led to a near shutdown of the air transport sector worldwide (ATAG 2020b; Pearce 2020), resulting in a net financial loss of approximately USD 118.5 billion (IATA 2020a). Whereas the air traffic forecasts out to 2050 are conservative, global demand is projected to recover to pre-pandemic levels by 2024, equivalent to an annual sectoral growth of 4.1% with an associated 2.9% annual increase in emissions (ATAG 2020b; WBG 2020; Pearce 2020).

Withal the intensifying pressure on the air transport sector to address its climate impact, the misrepresentation of data remains a common practice within the aviation community (Gössling and Peeters 2007). For example, a historical assessment on fuel efficiency of commercial aircraft conducted by Peeters et al. (2005) revealed that the gains used as benchmarks for the industry's technological achievements are inaccurate and misleading. Their study showed that contrarily to the 85% fuel efficiency claimed between 1960 and 2018 (ATAG 2020a), the last piston-engine aircraft of the mid-1950s were as fuel efficient as jets developed in the 1990s, and at least twice as efficient as the first jet-engine aircraft that replaced them (Peeters et al. 2005).

Another example concerns the adoption by the ICAO of a CO_2 emissions standard for aircraft[13], enforced to all new aircraft starting in 2028 (ICAO 2017). Notwithstanding its potential for reducing CO_2 emissions from the least fuel-efficient aircraft currently in service, the ICAO's

[12] The official acronym stands for "severe acute respiratory syndrome coronavirus 2".
[13] The standard applies to new aircraft type designs from 2020 and to aircraft type designs that are in production as of 2023. The Aeroplane CO_2 Emissions standard was included as a new Volume III in Annex 16 – Environmental Protection to the Convention on International Civil Aviation (Chicago Convention 1944).

standard is likely to prevent a backsliding in emissions rather than promoting innovation on structural efficiency (e.g. optimized aircraft design, lightweight materials) beyond business as usual[14] (Zheng and Rutherford 2020; ICCT 2017a). According to Zheng and Rutherford (2020), aircraft delivered in 2016 – at the time the ICAO's standard was finalized – already complied with the 2028 requirements, whereas those delivered in 2019 would have exceeded the standard by an average 6% fuel efficiency.

Data misrepresentation has been instrumental for creating and maintaining a positive image of aviation as socially desirable and economically all-important, which has encouraged the air transport community to historically underplay the sector's environmental impacts (Soria Baledón and Kosoy 2018; Piera 2015; Bridger 2013; Shaw and Thomas 2006). With few exceptions[15], the latter has resulted in a generalized understating of the urgency to implement more ambitious mitigation and adaptation strategies worldwide, while reinforcing a "psychology of denial" and inaction at the individual level[16], particularly for leisure travel (Cohen et al. 2011; Gössling and Peeters 2007; Shaw and Thomas 2006).

Additional information asymmetries and gaps precluding a better understanding of the climate impact of aviation stem from limitations to access protected data[17], along with the variety of epistemologies for measuring, allocating, assessing, verifying and reporting data collected by governments, industry, academia, NGOs, etc., that oftentimes is rendered incomparable (Gössling and Humpe 2020; Graver et al. 2020; Graver et al. 2019).

[14] Aircraft design is primarily driven by savings in operating costs, revenue increases, safety improvements, increased range and operative performance (Peeters et al. 2005). Though fuel efficiency is an essential component of aircraft design, purchase agreements by commercial operators are often determined by the overall operating costs all else unchanged (Hemmings 2016).

[15] Most notably in Europe, where the aviation industry, in addition to an increasing number of national governments, have committed to attain carbon-neutrality by 2050 (Soria Baledón et al. 2021).

[16] Knorr and Eisenkopf (2020) offer a detailed examination of the limited economic efficiency and ecological effectiveness of voluntary carbon offsetting schemes in the airline industry.

[17] For example, publicly available data on military jet fuel use is rather scant. According to Eyers et al. (2004), military aviation accounted for 6.7% of all aviation CO_2 in 2018; a figure comparable to the 7% estimate of Penner et al. (1999) for 2015.

This includes information on fuel use and emissions[18] (CO_2 and non-CO_2) by subsector (i.e. military, general aviation, business aviation, commercial passenger, belly freighters, dedicated cargo, humanitarian and medical assistance, disaster relief and firefighting operations), by scale (i.e. domestic, regional, international), by seating class (i.e. economy, business, first class), by stage length (i.e. short, medium, long-haul), by aircraft type (i.e. regional, narrowbody, widebody), etcetera.

Problem representations within the air transport sector that rest upon data misrepresentations, together with information gaps and asymmetries, can significantly avert effective mitigation efforts if a large share of aviation emissions is not covered by climate policies.

For example, the industry reported global emissions from commercial operations amounting to 650 $MtCO_2$ in 2005 (ATAG 2020b; ICAO 2019a) compared to 733 $MtCO_2$ reported by Lee et al. (2009) for the same year. Similarly, the industry anticipates emissions to reach 1,820 $MtCO_2$ by 2050 (ATAG 2020a) while Gössling and Humpe's (2020) forecast of 2,160 $MtCO_2$ is 16% less conservative. The latter is particularly relevant for policy-making since the 340 $MtCO_2$ forecast differential[19] is comparable to the aviation industry's target of reducing its global emissions to 325 $MtCO_2$ by 2050.

Emissions could also be measured based on the full lifecycle of air transport infrastructure and supply chains (manufacturing, operation, maintenance, etc.) which, according to a study from Chester and Horvath (2009), contribute with at least an additional 31% to the tailpipe emissions from CAF combustion. This approach would provide a more comprehensive understanding of the climate impact of aviation beyond the ~2.4% CO_2 contribution, with the purpose of setting more appropriate, realistic, fair and ambitious mitigation commitments and strategies required to limit global warming to 1.5°C.

[18] Piston-engine aircraft are still common in general aviation. Yet, there are very few studies on emissions from aircraft using aviation gasoline (avgas) and motor gasoline (mogas) as fuel (Thanikasalam et al. 2018; Strauss and González 1989).

[19] Pidcock and Yeo (2016) forecast emissions to exceed 2.5 $GtCO_2$ by 2050, leading to a differential equivalent to all reported emissions from commercial aviation in 2005.

2.3. Thinking "problematically" about alternative jet fuels

In 1997, the difficulties for treating and attributing transborder emissions from international aviation and shipping to single states, led to their exclusion from the Kyoto Protocol (Haag 2020; Murphy 2020; Piera 2015; Lyle 2014). Instead, the United Nations Framework Convention on Climate Change (UNFCCC) entrusted governments to work through the ICAO and the International Maritime Organization (IMO), for reducing greenhouse gas emissions from aviation and marine bunker fuels[20], respectively (FCCC/CP/1997/7/Add.1.D1/CP.3).

Withal the UNFCCC acknowledged the need for a global mechanism to address emissions from international aviation, the Kyoto Protocol did not contain any provisions (e.g. reduction targets, timeframe, limitations, exceptions) nor guidance for the ICAO to implement its new mandate (Piera 2018). This resulted in a narrow and protectionist approach to aviation growth (Lyle 2014), revealed by the increasing geopolitical tensions within the ICAO over the application of principles and criteria of the Kyoto regime and those contained in the Chicago Convention[21], for the purpose of setting emissions reduction targets without compromising fair competition (Piera 2018, 2015).

The perceived lack of progress on climate mitigation following the Kyoto Protocol, targeted international aviation as a potential source for climate financing through economic measures (IMF 2011) as well as by incorporating foreign aircraft operators into the EU Emissions Trading Scheme (EU ETS) (Piera 2015). Although this prompted the air transport industry and the ICAO to set global aspirational targets[22] in 2009 and 2010, respectively (ICAO 2014; ATAG 2012), the *weak* sustainable approach[23] embedded in the mitigation strategies resulting thereof, rest upon problem

[20] The UNFCCC also *urged* its Subsidiary Body for Scientific and Technological Advice (SBSTA), to investigate options for the future inclusion of international emissions in the overall greenhouse gas inventories of parties to the Convention (FCCC/CP/1997/7/Add.1.D2/CP.3).

[21] Namely, the principle of "common but differentiated responsibilities and respective capabilities of States" (CBDR) stipulated in the Kyoto Protocol, and the principle of non-discrimination implicit in the Chicago Convention. Piera (2015) offers a comprehensive and in-depth scholarly discussion on this particular subject.

[22] Targets are non-binding and not attributable to individual countries or aircraft operators. They are applicable only to commercial operations and those set by the ICAO are further restricted to international aviation. This distinction is relevant insofar the targets exclude emissions from military, general non-commercial aviation, humanitarian and medical assistance, disaster relief and firefighting operations, whose overall climate contributions remain unclear.

[23] The concept of weak sustainability refers to the replacement of natural capital by human capital (social and manufactured) for the preservation of economic growth. Conversely, a strong sustainability approach advocates for an economic development where natural capital and human capital are irreplaceable (Ayres et al. 2001; Gowdy 2000;

representations with underlying assumptions that overemphasize aviation's benefits, understate its environmental impacts and enshrine technological and market-based solutions (Soria Baledón and Kosoy 2018).

The industry targets set in 2009 by the International Air Transport Association (IATA) consist of: a) an average 1.5% annual improvement in fuel efficiency from 2009 until 2020, b) attaining carbon-neutral growth[24] (CNG) from 2020, and c) halving the sector's net CO_2 emissions by 2050 relative to 2005 levels (ATAG 2012). In 2010, the ICAO's 37th General Assembly endorsed the first two targets[25] and mandated its Council to explore the feasibility of a long-term climate goal for international aviation (ICAO A37-19), expected to be agreed upon in 2022 at its 41st session (ICAO A40-18).

The attainment of these sectoral targets has encompassed significant improvements in operations, navigation, technologies, the use of alternative jet fuels and the adoption in 2016 of the ICAO's Carbon Offsetting and Reduction Scheme for International Aviation, hereafter referred to as CORSIA, to indirectly mitigate emissions from international aviation's growth between 2021 and 2035 (IATA 2020b; ATAG 2020a; ICAO 2019a; ICAO A39-3).

But even under the most conservative air traffic scenario post-COVID-19, the overall sectoral emissions are anticipated to outpace the reductions out to 2050 (ATAG 2020b; Boeing 2020; ICAO A39-WP/55; Pidcock and Yeo 2016; AEF 2014), unless alternative fuels with carbon reduction potentials over 80% on a lifecycle basis become available in sufficient quantities to fully displace conventional fuels (Staples et al. 2018; ICAO CAAF/2-WP/06).

Goodland 1995). For an in-depth discussion of the social, economic and environmental implications of a weak sustainability approach within the air transport sector, see Soria Baledón and Kosoy (2018).

[24] The international aviation community defines carbon-neutral growth as an absolute decoupling of CO_2 emissions from economic sectoral growth.

[25] The Assembly increased the annual fuel efficiency target to 2 percent (ICAO A37-19). It is noteworthy to clarify that progress towards meeting the ICAO's targets is reported by its 193 contracting members since 2015 every 3 years, though their national State Action Plans. Aircraft operators directly report their progress to the IATA.

2.3.1. Alternative jet fuels: imperfect substitutes for CAF

Alternative jet fuels (AJF) refer to the variety of *drop-in* substitutes for petroleum-based fuels or conventional aviation fuels (CAF) that satisfy jet fuel form, fit, safety and performance requirements[26]. AJF are produced from biogenic feedstock sources (e.g. agronomic and lignocellulosic crops, algae, agricultural and forestry residues, residue lipids, biogenic fraction of municipal solid waste, biogas, CO_2 from direct air capture) via thermochemical and biochemical routes (Roth 2020; de Jong 2018; Chuck 2016; IATA 2015a). AJF from non-biogenic feedstock sources including unconventional petroleum (e.g. coal, natural gas, oilsands) and industrial off-gases, are known as lower carbon aviation fuels (LCAF) (Elgowainy et al. 2012; Hileman et al. 2009).

AJF have been approved for use in commercial aviation since 2009, with 7 conversion pathways currently certified[27] under ASTM D7566 *Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons* (see Table 2.1). But unlike CAF, the synthesized fraction of AJF, referred to as "synthetic paraffinic kerosene" (SPK) or "neat AJF", are blending components and thus, require melding with petroleum-based jet fuel to comply with ASTM D7566 as drop-in fuels.

Neat AJF contain almost no aromatics and have a limited mix of aliphatic hydrocarbons (see Figure 2.2) that result in lower volumetric energy content, higher freezing point, higher viscosity, poor seal swell performance, among others, leading to incompatibilities with aircraft fuel system components (Yang et al. 2019; Vozka et al. 2019; Khandelwal et al. 2018; Dorrington 2016; Chishty 2015; Novelli 2011).

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[26] The international aviation community uses the term sustainable aviation fuels (SAF) to refer to drop-in alternative fuels that meet verifiable sustainability standards. However, in the absence of a global standard that comprehensively addresses environmental protection from a strong sustainability perspective (Ayres et al. 2001; Gowdy 2000; Goodland 1995), the author considered the proposed term (AJF) to better represent the variety of drop-in substitutes for CAF.

[27] Additional conversion pathways are undergoing certification through ASTM D4054 *Standard Practice for Evaluation of New Aviation Turbine Fuels and Fuel Additives*.

Table 2.1. ASTM conversion pathways for alternative jet fuels

ASTM Pathway[a]	Date of approval[a]	Blending limit[a]	Biogenic feedstock options[b,c]	CO_2e savings**	Technology status[d]
FT-SPK Fischer-Tropsch Synthetic Paraffinic Kerosene	2009	Up to 50%	-Biomass: agricultural and forestry residues, lignocellulosic crops, municipal and wood-processing waste -PtL*: renewable CO_2 and H_2	-Biomass: 70-80%[b] -PtL: 70-100%[b,e]	-Biomass: Demonstration -PtL: Demonstration
HEFA-SPK Hydroprocessed Esters and Fatty Acids	2011	Up to 50%	Oleochemical crops, waste and residue lipids from plant and animal origin	80-90%[b,c]	Commercial
HFS-SIP Hydroprocessed Fermented Sugars to Synthetic Isoparaffins	2014	Up to 10%	Lignocellulosic and agricultural sugar crops	50%[e]	-Agricultural crops: pre-commercial -Lignocellulosic crops: Prototype
FT-SPK/A Fischer-Tropsch Synthetic Paraffinic Kerosene with aromatics	2015	Up to 50%	-Biomass: agricultural and forestry residues, lignocellulosic crops, municipal and wood-processing waste -PtL: renewable CO_2 and H_2	-Biomass: 70-80%[b] -PtL: 70-100%[b,e]	-Biomass: Demonstration -PtL: Demonstration
ATJ-SPK Alcohol-to-Jet Synthetic Paraffinic Kerosene	2016 for isobutanol 2018 for ethanol	Up to 50%	Agricultural and lignocellulosic crops and residues	60-80%[b,e]	Demonstration
CH-SK or CHJ Catalytic Hydrothermolysis Synthesized Kerosene	2020	Up to 50%	Oleochemical crops, waste and residue lipids from plant and animal origin	50%[f]	Demonstration
HC-HEFA or HHC-SPK Hydroprocessed Hydrocarbons, Esters and Fatty Acids Synthetic Paraffinic Kerosene	2020	Up to 10%	-Hydrocarbons: triterpenes from *Botryococcus braunii* (microalgae) -Biomass: oleochemical crops, waste and residue lipids from plant and animal origin	50%[g]	Demonstration

Source: a: ASTM D7566; b: ATAG 2020a; c: WEF 2020; d: Bauen et al. 2020; e: Roth 2020; f: Lew and Biddle 2014; g: Cox et al. 2014.

*Power-to-liquid. FT-SPK based on PtL is certified under ASTM if cobalt or iron catalysts are used for Fischer-Tropsch synthesis (ASTM D7566).

**GHG savings could strongly vary based on the LCA methodology used and on the intrinsic performance of each conversion pathway.

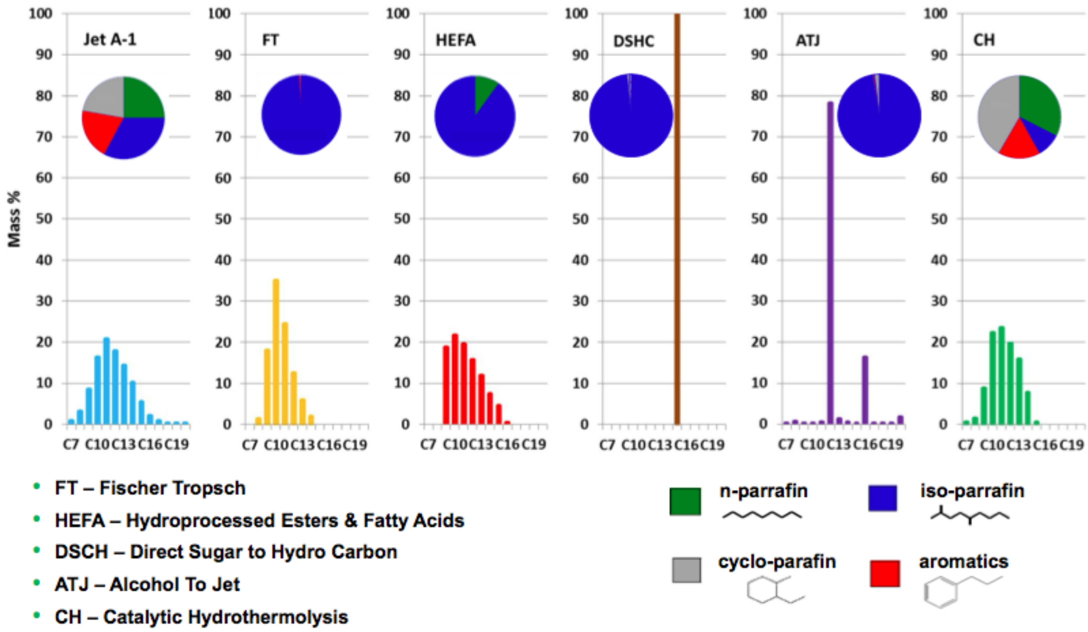

Figure 2.2. C-distribution and hydrocarbon composition for Jet A-1 and neat AJF (Chishty 2015)

Conversely, drop-in AJF are compatible and interchangeable with CAF and can be used "as is" in the existing distribution infrastructure, combustion engines, and fueling systems without additional modifications (Yang et al. 2019; ATAG 2017; IATA 2015b; Novelli 2011). For this reason, AJF manufactured, certified and released in compliance with ASTM D7566 requirements[28] will also meet the requirements of ASTM D1655 *Standard Specification for Aviation Turbine Fuels* and its equivalent standards elsewhere[29] (Rhode 2010).

Several AJF conversion pathways could yield considerable CO_2 reductions (Staples et al. 2018; ACRP 2018; El Takriti et al. 2017; Capaz and Seabra 2016; Wormslev et al. 2016; Alberici et al. 2014; Han et al. 2013; Bauen et al. 2009), but their mitigation potential is presently constrained by blending limits (see Table 2.1) to ensure AJF remain fit-for-purpose without compromising aircraft safety and performance.

[28] ASTM D7566 only applies to the point of batch origination whereas ASTM D1655 covers the entire supply chain from the refinery to the aircraft.
[29] *Supra* footnote 2.

In the past 10 years, AJF have been performance tested at 100% (Boeing 2021; Chan et al. 2016; ARA-CLG 2012) and newer engines[30] are expected to operate using neat AJF by 2030 (Rolls-Royce 2021; ATAG 2020a; WEF 2020; Bergthorson and Thomson 2015). Until then, the use of fuel additives could improve the physicochemical properties of AJF to allow for higher blends with CAF (Edwards 2020; Khandelwal et al. 2018; Repetto et al. 2016).

As for the wider climate impact of AJF, there is a limited understanding of the non-CO_2 effects of AJF blends on atmospheric chemistry and, though research shows an increased climate benefit from emissions reductions, the overall net RF effect of CO_2 and non-CO_2 emissions ultimately depends on the conversion pathway and feedstock used (Roth 2020; Khandelwal et al. 2018; Wormslev et al. 2016; Rojo et al. 2015; Stratton et al. 2011).

2.3.2. The AJF deployment trifecta: price, availability and sustainability

There are currently 9 airports[31] in Europe and North America regularly supplying AJF blends, over 6 billion litres of fuel in forward-purchase agreements[32] and more than 315,000 flights[33] have used AJF since 2011. As conversion pathways for AJF become commercially mature, production capacity is forecast to expand up to 3.5 billion litres per year by 2025, equivalent to 60-400 $MtCO_2$ avoided[34], and the market share of AJF is anticipated to reach a tipping point in the supply/price balance at 2% of the global aviation fuel stock (ATAG 2020c).

In 2018, approximately 14 million litres (0.01Mt) of AJF were blended with CAF (ATAG 2018) and in 2019, this figure nearly trebled to 40 million litres (0.03Mt), yet accounting for <0.01% of the global aviation fuel demand for the same year (ATAG 2020d; IATA 2020d).

By 2020, AJF production was expected to satisfy between 1.6% to 2.6% of CAF demand internationally (ICAO A39-WP/55; Bauen et al. 2009) and over past decade, several countries,

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[30] Such as the Rolls-Royce's Trent 1000 and Pearl 700 turbofan engines.
[31] Los Angeles and San Francisco in the US, Oslo and Bergen in Norway, and Stockholm (Arlanda and Bromma airports), Halmstad, Växjö and Kalmar in Sweden.
[32] https://aviationbenefits.org/environmental-efficiency/climate-action/sustainable-aviation-fuel on March 1, 2021.
[33] *Loc cit.*
[34] Contingent on their lifecycle emissions abatement potential.

regions and individual airlines had set aspirational AJF targets to be met as early as 2015[35] (van Dyk et al. 2017; IATA 2015a). The shortfalls in global production of AJF have been mainly attributed to: 1) the lack of dedicated policies and harmonized regulations to stimulate market development, and 2) to the limited availability of verifiable sustainable feedstocks for satisfying the global jet fuel demand using commercially mature technologies (WEF 2020; ATAG 2020a; ICAO 2019a; Deane and Pye 2018; Bosch et al. 2017).

At present, the minimum selling price (MSP) of AJF compared to CAF is twice to tenfold depending on the feedstock[36] and conversion pathway used (Roth 2020; de Jong 2018; Bann et al. 2017; Atsonios et al. 2015; Neuling and Kaltschmitt 2015; Bauen et al. 2009). This gap was widened by the low prices for CAF[37] throughout 2020 that, combined with prevalent low to non-taxation regimes (Gössling et al. 2017) and airlines' sensitivity to fuel price fluctuations, could hamper broad AJF uptake unless mandated. Furthermore, commercial deployment of AJF will still require investments for approximately USD 1.4 billion per annum[38] for attaining a 2% market share by 2025 (ATAG 2020a; IATA 2020d; Staples et al. 2018).

Historic market data indicate the possibility for CAF prices to sit below those of AJF in the future, however, the European Commission forecasts AJF to only reach 2.8% of the total fuel demand in Europe by 2050 in the absence of regulations and incentives; with similar projections made by the IATA for the rest of the world (EC IIA-Ares(2020)1725215). These projections already consider global decrements between 22% to 60% in AJF production costs, driven by economies of scale over and above those anticipated for renewable hydrogen and electricity production (ATAG 2020a).

[35] For a list of national and industry targets as well as a comprehensive overview of AJF global deployment projects and initiatives until 2015, see IATA (2015a). Additional and up-to-date information on AJF activities worldwide is accessible through the ICAO's Global Framework for Aviation Alternative Fuels (GFAAF) and ATAG's Sustainable aviation fuel websites at https://www.icao.int/environmental-protection/gfaaf/pages/default.aspx and https://aviationbenefits.org/environmental-efficiency/climate-action/sustainable-aviation-fuel, respectively.

[36] Feedstock represents between 45% and 90% of the total production cost of AJF.

[37] https://www.iata.org/en/publications/economics/fuel-monitor/ on March 1, 2021.

[38] For reference, in 2018 the U.S. government allocated USD 4 billion to renewable diesel under the Renewable Fuel Standard (RFS2) (IATA 2020d).

Conversion pathways certified under ASTM D7566 primarily depend on biogenic feedstocks (see Table 2.1), from which the hydroprocessing of esters and fatty acids (HEFA) is the only AJF production process commercially deployed as of 2021[39] (Roth 2020; ATAG 2020c; BioPortYVR 2020). Several studies have assessed the potential availability of biogenic sources for AJF production (Roth et al. 2018; El Takriti et al. 2017; Chuck et al. 2016; IATA 2015a; van Vuuren et al. 2009; Smeets et al. 2007), indicating the possibility for AJF to fully replace global demand for CAF in the future.

Yet, according to Searle and Malins (2016, 2015), a number of bioenergy assessments have failed to consider the logistics and the economics of feedstock production and processing, actual land availability, relevant biomass yields and harvesting potentials, and most importantly, only a few of these assessments have incorporated robust sustainability criteria into their models.

This point is essential insofar the use of certain biogenic feedstocks, whether from forestry or from dedicated bioenergy crops, does not eliminate the issue of direct and indirect land use change (LUC and ILUC, respectively) and their associated impacts on ecosystems, biodiversity, social welfare and emissions (Liu et al. 2014; IUCN 2009; Crosti 2009), as extreme land conversion could result in a large carbon debt and irreversible ecosystem loss (Chuck et al. 2016; Broch et al. 2013; Fargione et al. 2008).

Based on the most recent industry estimates (WEF 2020; ATAG 2020a), about 3.8 Gt/y^{-1} of biogenic feedstocks[40] (see Figure 2.3) could yield approximately 490Mt/y^{-1} AJF (~620 billion litres), equivalent to 1.2GtCO_2 annual reductions[41] by 2050. These production volumes could supply between 84% to 109% of the projected global jet fuel demand of 450-570Mt (~570-720 billion litres) by mid-century[42] (ATAG 2020a; ICAO CAAF/2-WP/06).

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[39] World Energy's biorefinery in Paramount (CA) is the only AJF dedicated facility in operation. All other biorefineries capable of producing AJF on demand, are optimized for road transport fuels and biochemicals within established markets.

[40] For a detailed description of the sustainability criteria applied for assessing the availability of biogenic feedstocks for AJF production, see WEF (2020a).

[41] Assuming a 77% CO_2 abatement potential on a lifecycle basis (ATAG 2020a).

[42] Future jet fuel demand is based on scenarios that combine improvements in infrastructure, operations, navigation, technologies, AJF uptake and the utilization of carbon offsets as an indirect CO_2 reduction measure. For details on the methodological framework used for the development of mitigation scenarios, see ATAG (2020a).

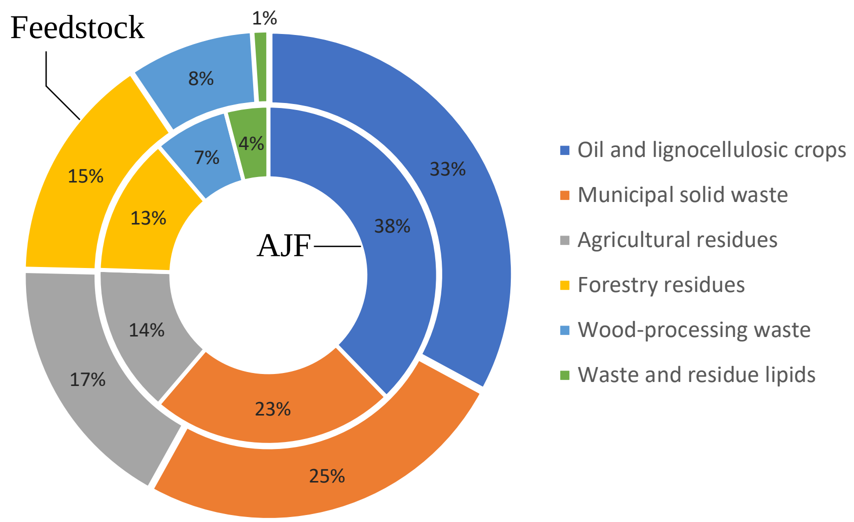

Figure 2.3. Global AJF potential out to 2050

AJF production could potentially comprise 185Mt from 1,255 Mt of dedicated oil and lignocellulosic crops, 115 Mt from 960 Mt of municipal solid waste (MSW), 70 Mt from 660 Mt of agricultural residues, 65 Mt from 580 Mt of forestry residues, 35 Mt from 320 of wood-processing waste, and 20 Mt from 40 Mt of waste and residue lipids (WEF 2020; ATAG 2020a).

There are several caveats to this forecast. First, the availability of feedstocks for reaching 490Mt of AJF per annum will be constrained by their competing uses from other sectors (most notably the biochemical industry and the road transport sector), where bioenergy is anticipated to largely contribute to the global mitigation and economy-wide decarbonization efforts for limiting global warming to 1.5°C above pre-industrial levels (IEA 2020b; Pavlenko et al. 2016).

Second, most conversion pathways – particularly those relying on biochemical routes – are optimized for co-products (e.g. renewable diesel) or intermediates (e.g. farnesene, ethanol, butanol) with higher market values and thus, are unlikely to apportion substantial AJF volumes until those markets become saturated (Jogi et al. 2020; van Dyk et al. 2019). Third, the extent to which the effects of climate change will affect future availability of land-based bioenergy feedstocks remains somewhat uncertain (Masson-Delmotte et al. 2018; Chuck et al. 2016) despite ceaseless developments and innovations on dedicated species and AJF conversion pathways.

2.3.3. Propulsion alternatives to the alternatives

The heightening interest and urgency to develop AJF production technologies that do not depend on land-based feedstock sources has prompted considerable R&D efforts in the use of hydrogen[43] (H_2) and the electrification of aircraft for propulsion. Though both alternatives could partially address some of the caveats and sustainability concerns discussed thus far when obtained from renewable sources (ICAO 2019a; Falter and Pitz-Paal 2017; Malins 2017; Ponater et al. 2006), they are not readily accessible options due to prevailing economic and technological barriers in addition to the long development cycles of aircraft, recurrent cost overruns and slow fleet turnover (IATA 2013; Jiang 2013).

The use of liquid hydrogen (LH_2) to fuel subsonic and supersonic aircraft has been investigated since the 1950s (Schäfer 2016), where successful flight demonstrators in the 1980s confirmed the possibility for cryogenic fuels to replace CAF (ICAO 2019a). Even so, prevailing barriers for broad uptake include safety concerns around the production, storage, handling and use of LH_2, the sustainability of fuel manufacturing processes (e.g. biomass gasification, water electrolysis, photocatalysis, etcetera), and the sizeable capital costs associated to the deployment of dedicated infrastructure (Baroutaji et al. 2019; Schäfer 2016; Najjar 2013).

Furthermore, new aircraft architectures are needed to compensate for the low volumetric density of LH_2 compared to CAF and AJF[44] (Baroutaji et al. 2019), which in turn requires certification of new aeroplane designs and operational infrastructure (IATA 2019). Presently, the ICAO has not issued standards (SARPs) for novel designs and propulsion architectures, including electric aircraft[45].

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[43] In gaseous or liquid form for combustion in jet engines, or as a power source for fuel cells.
[44] Conversely, LH_2 has a higher gravimetric density than CAF and AJF by nearly a factor of 3.
[45] Nonetheless, the ICAO closely follows technological developments in this field through its dedicated Electric and Hybrid Aircraft Platform for Innovation (E-HAPI) at: https://www.icao.int/environmental-protection/Pages/electric-aircraft.aspx

On the latter, the electrification of aeroplanes has rapidly evolved since the 1960s under the concepts of more electric aircraft (MOE) and electrical propulsion (Roland Berger 2017). The first concept has involved the progressive substitution of electricity for mechanical, hydraulic and pneumatic power sources for non-propulsive systems[46], whereas the second one has developed along three broad architectures: hybrid-electric, turbo-electric and all electric.

Although developments in electrical propulsion architectures keep gaining traction worldwide, batteries have not yet attained the minimum gravimetric density of 500Wh/kg to be commercially viable[47] (Roland Berger 2018), as their weight does not decrease over the flight cycle unlike liquid fuels in conventional propulsion. Additional challenges include achieving high recharging speeds, long battery lifecycles, improved conversion efficiencies, adequate hazard containment systems, among others[48] (ATAG 2020a; Roland Berger 2017). Most importantly, the electrification of aircraft will oblige the inclusion of sustainability considerations over the deployment of operational infrastructure, the lifecycle of batteries and the renewable sourcing of electricity in order to demonstrate its sustainability benefits (ICAO 2019a).

According to industry projections, both electrical and hydrogen propulsion configurations could become commercially available as early as 2025 for commuter flights (<60 min), followed by regional and short-haul flights (<120 min) in 2035-2040, and by limited applications for medium-haul flights (<150 min) as of 2050 (ATAG 2020a). The use of liquid fuels will remain the main energy source for long-haul flights (>150 min) based on the aforementioned technological, economic and sustainability constraints precluding the adoption of alternative propulsion architectures before 2050.

Meanwhile, both renewable electricity and hydrogen will be essential for the development and commercialization of power-to-liquid (PtL) and solar-thermochemical AJF (Schmidt et al. 2018; Malins 2017; Falter et al. 2016) that, in principle, could unlimitedly supply future global demand

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[46] For example, electricity has made actuation, flight and environmental control systems lighter, more efficient, flexible, easier to maintain (Roland Berger 2017).

[47] Presently, batteries can deliver between 150 to 250 Wh/kg whereas CAF and AJF have gravimetric densities 48 to 80 times higher at 12 kWh/kg (Roland Berger 2018, 2017).

[48] ATAG (2020a) offers a comprehensive analysis of the potential uptake barriers for technological innovations, including electrical propulsion, that have reached technical maturity.

for jet fuel. Assuming these conversion pathways will rely on carbon-neutral sources for electricity, hydrogen, carbon dioxide and fully decarbonized supply chains[49], PtL and solar-thermochemical AJF could achieve a 100% lifecycle CO_2 abatement potential[50] (Bauen et al. 2020; Falter and Pitz-Paal 2017; Malins 2017).

2.4. Alternative jet fuels and the energy-climate geopolitics

The uncertainty around jet fuel price volatility and supply shortages following the oil embargo in 1973 by the Organization of the Petroleum Exporting Countries (OPEC), impelled research on alternatives to CAF primarily in the US, with fluctuating government support and industry interest thereafter (Soria Baledón and Kosoy 2018; Schäfer 2016).

But it was not until the oil peak prices of 2007-2008, that AJF gained international attention when several test flights validated their technical feasibility and operational safety (CAAF/09-WP/23; IATA 2009). While the ICAO's advocacy for alternative fuels originally intended to mitigate airlines' financial risk by diversifying the fuel market (CAAF/09-WP/23; Palmer 2015), it also recognized the potential for AJF to enable international air transport operations with a lower climate impact (ICAO A36-22).

Over the past decade, the development of AJF has been progressively driven by concerns around the environmental repercussions of aviation's growth and less by the perennial fear of peak oil, where demonstrated sustainability of AJF is deemed imperative for several reasons. First and foremost, for encouraging governments to adopt policies and regulations conductive to short-term commercial deployment; second, to minimize the sector's reputational risk associated to the extensive effects of land use conversion; third, to standardize fuel purchasing requirements worldwide, and fourth, to stimulate innovation for next-generation AJF conversion pathways (Soria Baledón et al. 2021).

[49] According to Malins (2017), PtL AJF produced in the EU using current grid average electricity could treble their CO_2e intensity in reference to CAF. Falter and Pitz-Paal (2017) have also documented the sustainability challenges for scaling-up solar-thermochemical AJF production.
[50] For specific CO_2 lifecycle abatement potentials using a combination of conventional and alternative propulsion architectures, see Bauen et al. (2020).

Adherence to a robust set of sustainability criteria for AJF production has been challenged from the onset by the highly heterogeneous universe of voluntary and mandatory certification schemes and regulations across jurisdictions worldwide (IATA 2015a; Alberici et al. 2014; ICAO 2013). The adoption of CORSIA[51] in 2016, aimed at addressing this challenge by creating a global standard for the certification of sustainable AJF for international aviation; yet as of March 2021, only two principles (i.e. GHG savings and land conversion restrictions) have been approved by the ICAO's Council for demonstrating compliance with the scheme[52] (ICAO 2019b).

Aside widespread concerns about CORSIA's shortcomings by design (Lyle 2018; ICCT 2017b), the geopolitical ramifications thereof are significant. Notwithstanding the price gap between AJF and CAF makes it unlikely for a notable proportion of CORSIA's obligations to be met with alternative fuels without policies and regulations to bridge that gap[53], short-term production of CORSIA eligible fuels could result in large carbon debts, irreversible environmental damage and social welfare loss.

CORSIA also recognizes fossil-based aviation fuels that meet current sustainability criteria, known as lower carbon aviation fuels (LCAF), for demonstrating adherence to the scheme (ICAO 2019a, 2018). This could distort long-term market signal for AJF with high sustainability profiles because LCAF would not displace fossil-derived jet fuels. Furthermore, long-term direct GHG savings from AJF capable of ≥70% reductions on a lifecycle basis, would be forgone for indirect emissions savings (10-60% CO_2e) in other sectors (e.g. oil and gas).

[51] CORSIA is a global offsetting and reduction scheme for addressing the short-to-mid-term CO_2 emissions (2021-2035) from international aviation's growth that exceed the 2019 baseline (originally 2019/2020) for carbon-neutral growth after improvements in technology and operations (ICAO A40-19, A39-3). Environmental obligations under this market-based scheme can be met through the use of AJF (for in-sector reductions) that comply with the ICAO's approved sustainability criteria for CORSIA eligible fuels.
[52] Sustainability requirements include: CO_2e reductions ≥10% compared to the baseline, and the preservation of land with high carbon stock (ICAO 2019b). Additional requirements concerning water, soil, air, conservation, waste and chemicals, human and labour right, land use rights and land use, water use rights, local and social development and food security, are currently under discussion and will be subject to approval by the ICAO Council by the end of CORSIA's pilot phase (2023) at the latest.
[53] Also, the cost of offsetting carbon emissions is estimated to be 4 to 15 times lower than the cost of reducing emissions with AJF (ICAO 2016b).

The production of LCAF entails reductions in the carbon intensity of fossil-derived fuels by means of: a) upstream efficiencies and adoption of best practices[54] in conventional and unconventional petroleum refining processes (IEA 2020c; Masnadi et al. 2018; Brandt et al. 2018), b) co-processing of up to 5% biocrudes and biogenic lipids with middle distillates in conventional refineries (van Dyk et al. 2019), and c) recycling of industrial off-gases (Liew et al. 2016).

LCAF production routes are qualified under ASTM D1655 and D7566 standards, respectively. According to recent industry estimates, off-gas recycling from global steel plants could yield 45 Mt/y^{-1} LCAF (~57 billion litres) by 2050, equivalent to 85-114 $MtCO_2$ annual reductions[55] from the displacement of CAF (ATAG 2020a). Co-processing biobased feedstocks in petroleum refineries could yield additional CO_2 reductions, but the verifiable quantification of the renewable content in CAF remains problematic (van Dyk et al. 2019; Bhatt and Zhang 2018).

Reductions in the carbon intensity of CAF driven by increasingly ambitious economy-wide environmental policies and regulations internationally, could support cost-effective GHG reductions in the oil and gas and other industrial sectors (El-Houjeiri 2019; Brandt et al. 2018; Liew et al. 2016). However, the inclusion of LCAF in CORSIA risks supporting the continued global dependence on fossil-derived jet fuels – most notably in regions where the carbon intensity of CAF is already lower than the scheme's 89 gCO_2e/MJ baseline – instead of meaningfully contributing to the long-term mitigation goals of the aviation sector.

2.5. Final reflections for sustainable aviation development in post-normal times

Energy transitions of unprecedented scale are shaping a new geopolitical reality, facilitated by the exponential growth of renewables in most economic sectors (IRENA 2019). While this trend is anticipated to strengthen energy security internationally and to support the decarbonization of the global economy for decades to come, fossil fuels still account for nearly 85% of the world's primary energy consumption, with CAF representing ~8% of the total share (BP 2020).

[54] Such as reducing gas flaring as well as fugitive and venting emissions, integrating carbon capture and storage (CCS), etcetera.
[55] Assuming a lifecycle reduction potential between 60 to 80% CO_2, based on the carbon intensities of electricity production and of the fuel supply chain (ATAG 2020a).

Thereupon, this was the first study to use Foucault's thinking "problematically" method of analysis within a post-normal science (PNS) framework to: a) critically and reflexively review the discursive foundations of environmental policy in aviation, and b) to reassess the status, challenges and opportunities for AJF to close the carbon loop of this hard-to-abate sector. Though this review discussed some of the techno-economic elements relevant to the advancement and upscaling of AJF, it focused on identifying and analyzing common problem (mis)representations affecting policy-making internationally.

Whether by default or by design, data misrepresentation has contributed to the creation and reinforcement of a positive image of aviation as socially desirable and economically all-important. Together with information gaps and asymmetries, the problem representations emerging thereof have ensued a generalized understating of the urgency to implement more ambitious mitigation and adaptation strategies for addressing the environmental impacts of aviation. At the individual level, problem (mis)representations that overemphasize the benefits, belittle the impacts and enshrine technological and market-based solutions, have bolstered a "psychology of denial" in end-users, particularly for leisure travel.

Sustainable production of AJF is essential for supporting the energy transition of the aviation sector, which could be forestalled by the current design and operationalization framework for eligible fuels under the ICAO's CORSIA. Whilst the air transport industry has pledged to robust sustainability standards for global deployment of AJF, adherence solely to CORSIA's criteria encompasses extensive short and long-term social, environmental and economic risks.

First, short-term production of eligible AJF for international aviation could result in substantial carbon debts, irreversible environmental damage and social welfare loss. Second, the inclusion of LCAF as CORSIA eligible fuels distorts long-term market signal for AJF and risks supporting the continued global dependence on fossil-derived jet fuels.

Third, long-term direct GHG savings from AJF will be lost to indirect savings from LCAF production. Fourth, broad uptake of LCAF could hinder investment and innovation on next-generation AJF technologies with higher sustainability profiles. Fifth, LCAF will not displace fossil-derived fuels, therefore their adoption could increase the aviation's sector reputational risk. Last, the use of LCAF is incompatible with the economy-wide reductions needed to meet the carbon-neutrality targets for 2050, set by an increasing number of national and supranational jurisdictions globally.

Looking out to 2050 and beyond, the findings presented in this study underscore the relevance of critically interrogating the discursive foundations embedded in sustainability policies and regulations; as problem representations that rest upon data misrepresentations, information gaps and asymmetries, preclude a more comprehensive understanding of the environmental and climate impacts of aviation beyond its ~2.4% CO_2 contribution. Foremost, they can avert setting more appropriate, realistic, fair and ambitious mitigation commitments and adaptation strategies for a new geopolitical reality.

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Declaration of interest

The author has no conflicts of interest to disclose.

Literature cited

1. ACRP (2018), State of the industry report on air quality emissions from sustainable alternative jet fuels, National Academy of Sciences. Retrieved from: http://nap.edu/25095

2. AEF (2014, August 8), Demand for air travel will have to be limited to meet industry CO_2 targets. Retrieved from: https://www.aef.org.uk/2014/08/08/demand-for-air-travel-will-have-to-be-limited-to-meet-industry-co2-targets/

3. Alberici S., Spöttle M. and G. Toop (2014), Assessment of sustainability standards for biojet fuel, report prepared by ECOFYS Germany GmbH for the International Air Transport Association (IATA).

4. ARA-CLG (2012, October 29), ReadiJet® Alternative Fuel Takes Flight: the world's first jet aircraft powered by 100% unblended, renewable jet fuel that meets petroleum jet fuel specifications lands in Canada. Retrieved from: https://www.chevrontechnologymarketing.com/Documents/2012_CLG-ARA-NRCFlight_MediaRelease.pdf

5. Atsonios K., Kougioumtzis M.A., Panopoulos K.D. and E. Kakaras (2015), Alternative thermochemical routes for aviation biofuels via alcohols synthesis: Process modeling, techno-economic assessment and comparison, *Applied Energy*, 138:346-366.

6. ATAG (2021, March 1), Sustainable aviation fuel. Retrieved from: https://aviationbenefits.org/environmental-efficiency/climate-action/sustainable-aviation-fuel

7. ATAG (2020a), Waypoint 2050 (1st edition). Retrieved from: https://aviationbenefits.org/media/167187/w2050_full.pdf

8. ATAG (2020b), Blueprint for a green recovery. Retrieved from: https://aviationbenefits.org/media/167158/bgr20_final.pdf

9. ATAG (2020c), Aviation’s energy transition. Retrieved from: https://aviationbenefits.org/downloads/fact-sheet-5-aviations-energy-transition/

10. ATAG (2020d), Aviation: Benefits beyond borders. Retrieved from: https://aviationbenefits.org/media/167186/abbb2020_full.pdf

11. ATAG (2018), Aviation: Benefits beyond borders. Retrieved from: https://aviationbenefits.org/media/166344/abbb18_full-report_web.pdf

12. ATAG (2017), Beginner's guide to sustainable aviation fuel (3rd edition). Retrieved from: https://www.atag.org/component/attachments/attachments.html?id=604

13. ATAG (2012), Powering the future of flight: The six easy steps to growing a viable aviation biofuels industry. Retrieved from: http://www.atag.org/component/downloads/downloads/152.html

14. Ayres R.U., van den Bergh J.C.J.M. and J. M. Gowdy (2001), Strong versus weak sustainability: economics, natural sciences and “consilience”, *Environmental Ethics*, 23(2):155-168.

15. Bacchi, C.L. (2012), Why study problematizations? Making politics visible, *Open Journal of Political Science*, 2(1):1-8.

16. Bacchi C.L. (2009), *Analysing policy: What's the problem represented to be?*, Frenchs Forest: Pearson.

17. Bann S.J., Malina R., Staples M.D., Suresh P., Pearlson M., Tyner W.E., Hileman J.I. and S.R.H. Barret (2017), The costs of production of alternative jet fuel : A harmonized stochastic assessment, *Bioresource Technology*, 227:179-187.

18. Baroutaji A., Wilberforce T., Ramadan M. and A.G. Olabi (2019), Comprehensive investigation on hydrogen and fuel cell technology in the aviation and aerospace sectors, *Renewable and Sustainable Energy Reviews*, 106:31-40.

19. Bauen A., Bitossi N., German L., Harris A. and K. Leow (2020), Sustainable aviation fuels: status, challenges and prospects of drop-in liquid fuels, hydrogen and electrification in aviation, *Johnson Matthey Technology Review*, 64(3):263-278.

20. Bauen A., Howes J., Bertuccioli L. And C. Chudziak (2009), Review of the potential for biofuels in aviation, E4tech. Retrieved from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.170.8750&rep=rep1&type=pdf

21. Bergthorson J.M. and M.J. Thomson (2015), A review of the combustion and emissions properties of advanced transportation biofuels and their impact on existing and future engines, *Renewable and Sustainable Energy Reviews*, 42:1393-1417.

22. Bhatt A. and Y. Zhang (2018), Air pollutant emissions and regulatory implications of a biorefinery co-processing bio-oil in a petroleum refinery, NREL. Retrieved from: https://www.nrel.gov/docs/fy19osti/71238.pdf

23. Brandt A.R., Masnadi M.S., Englander J.G., Koomey J. and D. Gordon (2018), Climate-wise choices in a world of oil abundance, *Environmental Research Letters*, 13(4):044027.

24. BioPortYVR (2020), Toward a Made-in-BC Clean Fuel Supply Chain: Discussion paper. Retrieved from: https://bioportyvr.ca/wp-content/uploads/BioPortYVR-Discussion-Paper-Sep16-2020.pdf

25. Bosch J., de Jong S.A., Hoefnagels R. and R. Slade (2017), Aviation biofuels : strategically important, technically achievable, tough to deliver, Grantham Institute, Imperial College London. Retrieved from : https://www.imperial.ac.uk/media/imperial-college/grantham-institute/public/publications/briefing-papers/BP-23-Aviation-Biofuels.pdf

26. BP (2020), Statistical Review of World Energy 2020 (69^{th} edition). Retrieved from: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf

27. Brasseur G.P., Cox R.A., Hauglustaine D., Isaksen I., Lelieveld J., Lister D.H., Sausen R., Schumann U., Wahner A. and P. Wiesen (1998), European assessment of the atmospheric effects of aircraft emissions, *Atmospheric Environment*, 32:2329-2418.

28. Bray D. and H. von Storch (1999), Climate science: an empirical example of postnormal science, *Bulletin of the American Meteorological Society*, 80(3):439-456.

29. Bridger, R. (2013), *Plane truth: aviation's real impact on people and the environment*, London: Pluto Press.

30. Broch A., Hoekman S.K. and S. Unnasch (2013), A review of variability in indirect land use change assessment and modeling in biofuel policy, *Environmental Science & Policy*, 29:147-157.

31. Capaz R.S. and J.E.A. Seabra (2016), Life cycle assessment of biojet fuels, in Chuck, C.J. (ed.), *Biofuels for aviation: feedstocks, technology and implementation*, London: Academic Press, pp.279-294.

32. Chester M.V. and A. Horvath (2009), Environmental assessment of passenger transportation should include infrastructure and supply chains, *Environmental Research Letters*, 4(2):1-8.

33. Chan T.W., Chishty W.A., Canteenwalla P., Buote D. and C.R. Davison (2016), Characterization of emissions from the use of alternative aviation fuels, *Journal of Engineering for Gas Turbines and Power*, 138:1-9.

34. Chishty, W.A. (2015, September 21), Alternative Aviation Fuels and the Certification Process, National Research Council Canada, BioFuelNet Canada's Biojet Course, Montreal. [PowerPoint slides]

35. Chuck, C.J. (ed.) (2016), *Biofuels for aviation: feedstocks, technology and implementation*, London: Academic Press.

36. Cohen S.A., Higham J.E.S. and C.T. Cavaliere (2011), Binge flying: behavioural addiction and climate change, *Annals of Tourism Research*, 38(3):1070-1089.

37. Cox K., Renouf M., Dargan A., Turner C. and D. Klein-Marcuschamer (2014), Environmental life cycle assessment (LCA) of aviation biofuel from microalgae, Pongamia pinnata and sugarcane molasses, *Biofuels, bioproducts & biorefining*, 8(4):579-593.

38. Creek, R.J. (1989), Manufacturing aviation gasoline, in Strauss K.H. and C. González (eds.), *Future Fuels for General Aviation*, ASTM STP 1048, Philadelphia: ASTM, pp.5-16.

39. Crosti, R. (2009), Invasiveness of biofuel crops and potential harm to natural habitats and native species, report prepared for the Convention on the Conservation of European Wildlife and Natural Habitats of the Council of Europe. Retrieved from: http://www.globalbioenergy.org/uploads/media/1012_CE_-_Invasiveness_of_biofuel_crops_and_potential_harm_to_natural_habitats_and_native_species.pdf

40. Csonka, S. (2015, September 21), An overview of concepts related to the development and commercialization of sustainable alternative jet fuel, BioFuelNet Canada's Biojet Course, Montreal. [PowerPoint slides]

41. Dankel D.J., Vaage N.S. and J.P. van der Sluijs (2017), Post-normal science in practice, *Futures*, 91:1-4.

42. de Jong, S.A. (2018), *Green horizons : On the production costs, climate impact and future supply of renewable jet fuels*, Utrecht : Copernicus Institute of Sustainable Development.

43. Deane J.P. and S. Pye (2018), Europe's ambition for biofuels in aviation. A strategic review of challenges and opportunities, *Energy Strategy Reviews*, 20:1-5.

44. Dorrington, G.E. (2016), Certification and performance: what is needed from an aviation fuel?, in Chuck, C.J. (ed.), *Biofuels for aviation: feedstocks, technology and implementation*, London: Academic Press, pp.35-44.

45. Edwards, J.T. (2020), Jet fuel properties, Air Force Research Laboratory, AFRL-RQ-WP-TR-2020-0017. Retrieved from: https://apps.dtic.mil/sti/pdfs/AD1093317.pdf

46. Elgowainy A., Han J., Wang M., Carter N., Stratton R., Hileman J., Malwitz A. and S. Balasubramanian (2012), Life-cycle analysis of alternative aviation fuels in GREET, ANL/ESD/12-8. Retrieved from: https://publications.anl.gov/anlpubs/2016/05/127787.pdf

47. El-Houjeiri, H.M. (2019, April 30), Aviation climate policy and lower carbon aviation fuel, First ICAO Stocktaking Seminar toward the 2050 Vision for Sustainable Aviation Fuels, Montreal. [PowerPoint slides] Retrieved from: https://www.icao.int/Meetings/SAFStocktaking/Documents/ICAO%20SAF%20Stocktaking%202019%20-%20AI2-7%20Hassan%20ElHoujeiri.pdf

48. El Takriti S., Pavlenko N. and S. Searle (2017), Mitigating international aviation emissions. Risks and opportunities for alternative jet fuels, ICCT. Retrieved from:

https://theicct.org/sites/default/files/publications/Aviation-Alt-Jet-Fuels_ICCT_White-Paper_22032017_vF.pdf

49. Etkin D. and E. Ho (2007), Climate change: perceptions and discourses of risk, *Journal of Risk Research*, 10(5):623-641.

50. Eyers C.J., Norman P., Middel J., Plohr M., Michot T., Atkinson K. and R.A. Christou (2004), AERO2k global aviation emissions inventory for 2002 and 2025. Retrieved from: https://www.yumpu.com/en/document/read/7313363/aero2k-global-aviation-emissions-inventories-for-2002-and-2025

51. Falter C. and R. Pitz-Paal (2017), Water footprint and land requirement of solar thermochemical jet-fuel production, *Environmental Science & Technology*, 51:12938-12947.

52. Falter C., Batteiger V. and A. Sizmann (2016), Climate impact and economic feasibility of solar thermochemical jet fuel production, *Environmental Science & Technology*, 50(1):470-477.

53. Fargione J., Hill J., Tilman D., Polasky S. and P. Hawthorne (2008), Land clearing and the biofuel carbon debt, *Science*, 319(5867):1235-1238.

54. Foucault, M. (1988), The concern for truth, in L.D. Kritzman (ed.), *Michel Foucault: politics, philosophy, culture. Interviews and other writings 1977-1984*, New York: Roultledge, pp.255-267.

55. Foucault, M. (1977), *Language, counter-memory, practice: selected essays and interviews*, in D.F. Bouchard (ed.), New York: Cornell University Press.

56. Funtowicz S.O. and J.R. Ravetz (2003), Post-Normal Science, *Encyclopedia of Ecological Economics*, International Society for Ecological Economics (ISEE). Retrieved from: http://isecoeco.org/pdf/pstnormsc.pdf

57. Funtowicz S.O. and J.R. Ravetz (1994), The worth of a songbird: ecological economics as a post-normal science, *Ecological Economics*, 10:197-207.

58. Funtowicz S.O. and J.R. Ravetz (1993), Science for the post-normal age, *Futures*, 25(7):739-755.

59. González, C. (1989), A proposal for fuel specification activities relating to general aviation intermittent combustion engines, in Strauss K.H. and C. González (eds.), *Future Fuels for General Aviation*, ASTM STP 1048, Philadelphia: ASTM, pp.153-165.

60. Goodland, R. (1995), The concept of environmental sustainability, *Annual Review of Ecology and Systematics*, 26:1-24.

61. Gowdy, J.M. (2000), Terms and concepts in ecological economics, *Wildlife Society Bulletin*, 28(1):26-33.

62. Graver B., Rutherford D. and S. Zheng (2020), CO_2 emissions from commercial aviation: 2013, 2018, and 2019, ICCT. Retrieved from: https://theicct.org/sites/default/files/publications/CO2-commercial-aviation-oct2020.pdf

63. Graver B., Zhang K. and D. Rutherford (2019), CO_2 emissions from commercial aviation 2018, ICCT. Retrieved from: https://theicct.org/sites/default/files/publications/ICCT_CO2-commercl-aviation-2018_20190918.pdf

64. Grewe V. (2020), Aviation emissions and climate impacts, in Fichert F., Forsyth P. and H.M. Niemeier (eds.), *Aviation and climate change: economic perspectives on greenhouse gas reduction policies*, London/New York: Routledge, pp.4-15.

65. Gössling S. and A. Humpe (2020), The global scale, distribution and growth of aviation: implications for climate change, *Global Environmental Change*, 65:1-12.

66. Gössling S., Fichert F. and P. Forsyth (2017), Subsidies in aviation, *Sustainability*, 9(8):1295.

67. Gössling S. and P.M. Peeters (2007), "It does not harm the environment!" An analysis of industry discourses on tourism, air travel and the environment, *Journal of Sustainable Tourism*, 15(4):402-217.

68. Haag, K. (2020), International action and the role of ICAO, in Fichert F., Forsyth P. and H.M. Niemeier (eds.), *Aviation and climate change: economic perspectives on greenhouse gas reduction policies*, London/New York: Routledge, pp.104-116.

69. Haikola S., Hansson A. and J. Anshelm (2019), From polarization to reluctant acceptance-bioenergy with carbon capture and storage (BECCS) and the post-normalization of the climate debate, *Journal of Integrative Environmental Sciences*, 16(1):45-69.

70. Han J., Elgowainy A., Cai H. And M.Q. Wang (2013), Life-cycle analysis of bio-based aviation fuels, *Bioresource Technology*, 150:447-456.

71. Hemmings, B. (2016), European Parliament briefing: aviation emissions and ICAO's CO_2 standard for new aircraft, Transport & Environment. Retrieved from: https://www.transportenvironment.org/sites/te/files/publications/TE%20Brief%20on%20ICAO%20CO2%20Standard%20Jan%202015.pdf

72. Hileman J.I., Ortiz D.S., Bartis J.T., Wong H.M., Donohoo P.E., Weiss M.A. and I.A. Waitz (2009), Near-term feasibility of alternative jet fuels, RAND Corporation, TR-554-FAA. Retrieved from: https://www.rand.org/pubs/technical_reports/TR554.html

73. IATA (2021, March 1), Jet fuel price monitor. Retrieved from: https://www.iata.org/en/publications/economics/fuel-monitor/

74. IATA (2020a, November 24), “Deep losses continue into 2021”, Press release no.95. Retrieved from: https://www.iata.org/en/pressroom/pr/2020-11-24-01/

75. IATA (2020b), Aviation and climate change fact sheet. Retrieved from: https://www.iata.org/en/iata-repository/pressroom/fact-sheets/fact-sheet--climate-change/

76. IATA (2020c), Sustainable aviation fuel (SAF) fact sheet. Retrieved from: https://www.iata.org/contentassets/8dc7f9f4c38247ae8f007998295a37d5/saf_general-fact-sheet_advocacy_june2020.pdf

77. IATA (2020d), Proceedings from the Sustainability and Environment Advisory Council meeting [SEAC/2], March 24-25.

78. IATA (2019), Liquid hydrogen as a potential low-carbon fuel for aviation. Fact sheet 7. Retrieved from: https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/fact_sheet7-hydrogen-fact-sheet_072020.pdf

79. IATA (2015a), Sustainable aviation fuel roadmap. Retrieved from: https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/safr-1-2015.pdf

80. IATA (2015b), Guidance Material for Sustainable Aviation Fuel Management. Retrieved from: https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/iata20guidance20material20for20saf.pdf

81. IATA (2009, December 8), “Halving emissions by 2050: aviation brings its targets to Copenhagen”, Press release no.54. Retrieved from: http://www.iata.org/pressroom/pr/Pages/2009-12-08-01.aspx

82. IATA (2013), Technology Roadmap (4th ed.). Retrieved from: https://aviation.report/Resources/Whitepapers/6e0df8d7-f381-4a56-bef4-3f83fe8f65e1_IATA%20TECHNOLOGY%20ROADMAP%202013.pdf

83. ICAO (2021, March 1), Global Framework for Aviation Alternative Fuels. Retrieved from: https://www.icao.int/environmental-protection/gfaaf/pages/default.aspx

84. ICAO (2019a), Destination green: the next chapter. Retrieved from: https://www.icao.int/environmental-protection/Documents/ICAO-ENV-Report2019-F1-WEB%20%281%29.pdf

85. ICAO (2019b), CORSIA Sustainability criteria for CORSIA eligible fuels. Retrieved from: https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2005%20-%20Sustainability%20Criteria.pdf

86. ICAO (2018), Annex 16 to the Convention on International Civil Aviation – Environmental Protection. Volume IV – Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). Retrieved from: https://www.unitingaviation.com/publications/Annex-16-Vol-04/#page=1

87. ICAO (2017, March 6), ICAO Council adopts new CO_2 emissions standard for aircraft. Retrieved from: https://www.icao.int/Newsroom/NewsDoc2017fix/COM.05.17.EN.pdf

88. ICAO (2016a), Environmental report: on board a sustainable future. Retrieved from: https://www.icao.int/environmental-protection/Documents/ICAO%20Environmental%20Report%202016.pdf

89. ICAO (2016b), Environment Advisory Group meeting (EAG/15). Results of technical analyses by CAEP, January 20-21, Montreal. [PowerPoint slides] Retrieved from: https://www.icao.int/Meetings/HLM-MBM/Documents/EAG15_CAEP%20Technical%20Analyses.pdf

90. ICAO (2014), Overview of alternative jet fuels in 2014, published in IATA, *Report on alternative fuels*. Retrieved from: https://www.icao.int/environmental-protection/GFAAF/Documents/Overview%20of%20Alternative%20Jet%20Fuels%20in%202014.pdf

91. ICAO (2013), The challenges for the development and deployment of sustainable alternative fuels in aviation. Outcomes of ICAO's SUSTAF Experts Group. Retrieved from: https://www.icao.int/environmental-protection/GFAAF/Documents/ICAO%20SUSTAF%20experts%20group%20outcomes_release%20May2013.pdf

92. ICCT (2017a), International Civil Aviation Organization's CO_2 standard for new aircraft. https://theicct.org/sites/default/files/publications/ICCT-ICAO_policy-update_revised_jan2017.pdf

93. ICCT (2017b), International Civil Aviation Organization's Carbon Offset and Reduction Scheme for International Aviation (CORSIA). Retrieved from: https://theicct.org/sites/default/files/publications/ICAO%20MBM_Policy-Update_13022017_vF.pdf

94. IEA (2020a), CO_2 emissions from fuel combustion, IEA Atlas of Energy. Retrieved from: http://energyatlas.iea.org/#!/tellmap/1378539487

95. IEA (2020b), Renewables 2020. Analysis and forecast to 2025. Retrieved from: https://webstore.iea.org/download/direct/4234

96. IEA (2020c), The oil and gas industry in energy transitions. Retrieved from: https://webstore.iea.org/download/direct/2935

97. IMF (2011), Market-based instruments for international aviation and shipping as a source of climate finance. Background paper for the report to the G20 on mobilizing sources of climate finance. Retrieved from: https://www.imf.org/external/np/g20/pdf/110411a.pdf

98. IRENA (2019), A new world. The geopolitics of the energy transformation. Retrieved from: http://geopoliticsofrenewables.org/assets/geopolitics/Reports/wp-content/uploads/2019/01/Global_commission_renewable_energy_2019.pdf

99. IUCN (2009), Guidelines on Biofuels and Invasive Species. Retrieved from: https://cmsdata.iucn.org/downloads/iucn_guidelines_on_biofuels_and_invasive_species_.pdf

100. Jiang H. (2013), "Key findings on airplane economic life", The Boeing Company. Retrieved from: http://www.boeing.com/assets/pdf/commercial/aircraft_economic_life_whitepaper.pdf

101. Jogi R., Mäki-Arvela P., Virtanen P. And J.-P. Mikkola (2020), A sustainable bio-jet fuel: an alternative energy source for aviation sector, in Verma, P. (ed.), *Biorefineries: a step towards renewable and clean energy*, Singapore: Springer, pp:465-496.

102. Khandelwal B., Wijesinghe C.J. and S. Sriraman (2018), Effect of alternative fuels on emissions and engine compatibility, in Runchal A.K., Gupta A.K., Kushari A., De A. and S.K. Aggarwal (eds.), *Energy for propulsion. A sustainable technologies approach*, Singapore: Springer, pp.27-50.

103. Knorr A. and A. Eisenkopf (2020), Voluntary carbon offset schemes in the airline industry. Why did they fail?, in Fichert F., Forsyth P. and H.M. Niemeier (eds.), *Aviation and climate change: economic perspectives on greenhouse gas reduction policies*, London/New York: Routledge, pp.130-144.

104. Kolmes, S.A. (2011), Ground-level pollution, invasive species and emergent diseases, in E. A. Hoppe (ed.), *Ethical issues in aviation*, Burlington: Ashgate, pp.257-265.

105. Kuhn, T. (1962), *The structure of scientific revolutions*, Chicago: University of Chicago Press.

106. Lee D.S., Fahey D.W., Skowron A., Allen M.R., Burkhardt U., Chen Q., Doherty S.J., Freeman S., Forster P.M., Fuglestvedt J., Gettelman A., De León R.R., Lim L.L., Lund M.T., Millar R.J., Owen B., Penner J.E., Pitari G., Prather M.J., Sausen R. and L.J. Wilcox (2021), The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018, *Atmospheric Environment*, 244:117834.

107. Lee D.S., Fahey D.W., Forster P.M., Newton P.J., Wit R.C.N., Lim L.L., Owen B. and R. Sausen (2009), Aviation and global climate change in the 21st century, *Atmospheric Environment*, 43(22-23):3520-3537.

108. Lew L. and T. Biddle (2014), Evaluation of ARA Catalytic Hydrothermolysis (CH) fuel, report prepared by Pratt & Whitney for FAA's CLEEN Program. Retrieved from: https://www.faa.gov/about/office_org/headquarters_offices/apl/research/aircraft_technology/cleen/reports/media/PW_ARA_Final.pdf

109. Liew F., Martin M.E., Tappel R.C., Heijstra B.D., Mihalcea C. and M. Köpke (2016), Gas fermentation – A flexible platform for commercial scale production of low-carbon-fuels and chemicals from waste and renewable feedstocks, *Frontiers in Microbiology*, 7:694.

110. Liu Y., Xu Y., Zhang F., Yun J. and Z. Shen (2014), The impact of biofuel plantation on biodiversity: a review, *Chinese Science Bulletin*, 59:4639-4651.

111. Lyle (2018), Beyond the ICAO's CORSIA: Towards a more climatically effective strategy for mitigation of civil-aviation emissions, *Climate Law*, 8(1-2):104-127.

112. Lyle, C. (2014, February 6), Mitigating international air transport emissions through a global measure: time for some lateral thinking, GreenAir Online. Retrieved from: http://www.greenaironline.com/news.php?viewStory=1820

113. Malins, C. (2017), What role is there for electrofuel technologies in European transport's low carbon future?, report prepared by Cerulogy for T&E. Retrieved from: https://www.transportenvironment.org/sites/te/files/publications/2017_11_Cerulogy_study_What_role_electrofuels_final_0.pdf

114. Masnadi M.S., El-Houjeiri H.M., Schunack D., Li Y., Englander J.G., Badahdah A., Monfort J.-C., Anderson J.E., Wallington T.J., Bergerson J.A., Gordon D., Koomey J., Przesmitzki S., Azevedo I.L., Bi X.T., Duffy J.E., Heath G.A., Keoleian G.A., McGlade C., Meehan D.N., Yeh S., You F., Wang M. and A.R. Brandt (2018), Global carbon intensity of crude oil production, *Science*, 361(6405):851-853.

115. Masson-Delmotte V., Zhai P., Pörtner H.-O., Roberts D., Skea J., Shukla P.R., Pirani A., Moufouma-Okia W., Péan C., Pidcock R., Connors S., Matthews J.B.R., Chen Y., Zhou X., Gomis M.I., Lonnoy E., Maycock T., Tignor M. and T. Waterfield (eds.) (2018), Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development and efforts to eradicate poverty. Retrieved from: https://www.ipcc.ch/sr15/download/

116. Moore R.H., Thornhill K.L., Weinzierl B., Sauer D., D'Ascoli E., Kim J., Lichtenstern M., Scheibe M., Beaton B., Beyersdorf A.J., Barrick J., Bulzan D., Corr C.A., Crosbie E., Jurkat T., Martin R., Riddick D., Shook M., Slover G., Voigt C., White R., Winstead E., Yasky R., Ziemba L.D., Brown A., Schlager H. & B.E. Anderson (2017), Biofuel blending reduces particle emissions from aircraft engines at cruise conditions, *Nature*, 543:411-415.

117. Murphy, A. (2020), Inclusion of international aviation emissions under the Paris Agreement's Nationally Determined Contributions (NDCs), in Fichert F., Forsyth P. and

H.M. Niemeier (eds.), *Aviation and climate change: economic perspectives on greenhouse gas reduction policies*, London/New York: Routledge, pp.221-228.

118. Najjar, Y.S.H. (2013), Hydrogen safety: the road toward green technology, *International Journal of Hydrogen Energy*, 38(25):10716-10728.

119. Neuling U. and M. Kaltschmitt (2015), Conversion routes for production of biokerosene: status and assessment, *Biomass Conversion and Biorefinery*, 5:367-385.

120. Novelli, P. (2011), Sustainable Way for Alternative Fuels and Energy in Aviation (SWAFEA), report prepared for the European Commission's Directorate General for Mobility and Transport, Retrieved from: https://www.icao.int/environmental-protection/GFAAF/Documents/SW_WP9_D.9.1%20Final%20report_released%20July2011.pdf

121. Palmer, Walter J. (2015), *Will sustainability fly? Aviation fuel options in a low-carbon world*, New York: Routledge.

122. Pavlenko N., El Takriti S., Malins C. and S. Searle (2016), Beyond the biofrontier: balancing competing uses of the biomass resource. ICCT. Retrieved from: https://theicct.org/publications/beyond-biofrontier-balancing-competing-uses-biomass-resource

123. Pearce, B. (2020, April 14), COVID-19 updated impact assessment, IATA. [PowerPoint slides] Retrieved from: https://www.iata.org/en/iata-repository/publications/economic-reports/covid-fourth-impact-assessment/

124. Peeters P.M., Middel J. and A. Hoolhorst (2005), Fuel efficiency of commercial aircraft: an overview of historical and future trends, NLR-CR-2005-669. Retrieved from: https://www.transportenvironment.org/sites/te/files/media/2005-12_nlr_aviation_fuel_efficiency.pdf

125. Penner J.E., Lister D.H., Griggs D.J., Dokken D.J., and M. McFarland (eds.) (1999), *Aviation and the Global Atmosphere: A special report of the Intergovernmental Panel on Climate Change*, United Kingdom: Cambridge University Press.

126. Pidcock R. and S. Yeo (2016, August 8), “Analysis: aviation could consume a quarter of 1.5C carbon budget by 2050”. Retrieved from: https://www.carbonbrief.org/aviation-consume-quarter-carbon-budget

127. Piera, A.J. (2018), Getting to global cooperation: ICAO and climate change, in de Mestral A.L.C., Fitzgerald P. and T. Ahmad (eds.), *Sustainable development, international aviation and treaty implementation*, Cambridge/New York: Cambridge University Press, pp.247-281.

128. Piera, A.J. (2015), *Greenhouse gas emissions from international aviation: legal and policy challenges*, The Hague: Eleven International Publishing.

129. Ponater M., Pechtl S., Sausen R., Schumann U. and G. Hüttig (2006), Potential of the cryoplane technology to reduce aircraft climate impact: a state-of-the-art assessment, *Atmospheric Environment*, 40:6928-6944.

130. Ravetz, J.R. (1971), *The roots of present-day science. An essay*, United Kingdom: The Open University.

131. Repetto S.L., Costello J.F. and D. Parmenter (2016), Current and potential aviation additives for higher biofuel blends in Jet A-1, in Chuck, C.J. (ed.), *Biofuels for aviation: feedstocks, technology and implementation*, London: Academic Press, pp.261-275.

132. Rhode, J. (2010), Aviation fuels, in Rand, S.J. (ed.), *Significance of tests for petroleum products* (8th edition), West Conshohocken: ASTM International.

133. Rojo C., Vancassel X., Mirabel P., Ponche J.L. and F. Garnier (2015), Impact of alternative jet fuels on aircraft-induced aerosols, *Fuel*, 144:335-341.

134. Roland Berger (2018), Aircraft electrical propulsion: onwards and upwards. Retrieved from: https://www.rolandberger.com/en/Insights/Publications/Electrical-propulsion-ushers-in-new-age-of-innovation-in-aerospace.html

135. Roland Berger (2017), Aircraft electrical propulsion: the next chapter of aviation? Retrieved from: https://www.rolandberger.com/zh/Publications/New-developments-in-aircraft-electrical-propulsion.html

136. Rolls-Royce (2021, February 1), Rolls-Royce conducts first tests of 100% sustainable aviation fuel for use in business jets. Retrieved from: https://www.rolls-royce.com/media/press-releases/2021/01-02-2021-business-aviation-rr-conducts-first-tests-of-100-precent-sustainable-aviation-fuel.aspx

137. Roth, A. (2020), Renewable fuels for aviation, in Fichert F., Forsyth P. and H.M. Niemeier (eds.), *Aviation and climate change: economic perspectives on greenhouse gas reduction policies*, London/New York: Routledge, pp.16-46.

138. Roth A., Riegel F. and V. Batteiger (2018), Potentials of biomass and renewable energy: the question of sustainable availability, in Kaltschmitt M. and U. Neuling (eds.), *Biokerosene: status and prospects*. Berlin: Springer, pp.95-122.

139. Schmidt P., Batteiger V., Roth A., Weindorf W. and T. Raksha (2018), Power-to-liquids as renewable fuel option for aviation: a review, *Chemie Ingenieur Technik*, 90(1-2):127-140.

140. Schobert, H.H. (ed.) (2013), *Chemistry of fossil fuels and biofuels*, Cambridge: Cambridge University Press.

141. Schäfer, A.W. (2016), The prospects for biofuels in aviation, in Chuck, C.J. (ed.), *Biofuels for aviation: feedstocks, technology and implementation*, London: Academic Press, pp.3-16.

142. Searle S. and C. Malins (2016), Waste and residue availability for advanced biofuel production in EU Member States, *Biomass and Bioenergy*, 89:2-10.

143. Searle S. and C. Malins (2015), A reassessment of global bioenergy potential in 2050, *GCB-Bioenergy*, 7(2):328-336.

144. Shaw S. and C. Thomas (2006), Social and cultural dimensions of air travel demand: hyper-mobility in the UK?, *Journal of Sustainable Tourism*, 14(2):209-215.

145. Smeets E.M.W., Faaij A.P.C., Lewandowski I.M. and W.C. Turkenburg (2007), A bottom-up assessment and review of global bio-energy potentials to 2050, *Progress in Energy and Combustion Science,* 33(1):56-106.

146. Soria Baledón M., Trudel M. and N. Kosoy (2021), Alternative jet fuels and climate geopolitics: *what*, *why* does it and *who* matters in the environmental policy-making process, *International Journal of Sustainable Transportation*.

147. Soria Baledón M. and N. Kosoy (2018), “Problematizing” carbon emissions from international aviation and the role of alternative jet fuels in meeting ICAO’s aspirational goals, *Journal of Air Transport Management*, 71:130-137.

148. Staples M.D., Malina R., Suresh P., Hileman J.I. and S.R.H. Barrett (2018), Aviation CO_2 emissions reductions from the use of alternative jet fuels, *Energy Policy*, 114(C) :342-354

149. Strand, R. (2017), Post-normal science, in C.L. Spash (ed.), *Routledge handbook of ecological economics: nature and society*, London: Routledge, pp.288-298.

150. Stratton R.W., Wolfe P.J. and J.I. Hileman (2011), Impact of aviation non-CO_2 combustion effects on the environmental feasibility of alternative jet fuels, *Environmental Science & Technology*, 45(24):10736-10743.

151. Strauss, K.H. (2003), Aviation fuels, in Totten, G.E. (ed.), *Fuels and lubricants handbook: technology, properties, performance and testing*, ASTM MNL 37, West Conshohocken: ASTM International, pp.89-114.

152. Strauss K.H. and C. González (eds.) (1989), *Future Fuels for General Aviation*, ASTM STP 1048, Philadelphia: ASTM.

153. Thanikasalam K., Rahmat M., Mohammad Fahmi A.G., Zulkifli A.M., Noor Shawal N., Ilanchelvi K., Ananth M. and R. Elayarasan (2018), Emissions of piston engine aircraft using aviation gasoline (avgas) and motor gasoline (mogas) as fuel – a review, *IOP Conference Series: Materials Science and Engineering*, 370:012012.

154. The Boeing Company (2021, January 22), Boeing commits to deliver commercial airplanes ready to fly on 100% sustainable fuels. Retrieved from: https://boeing.mediaroom.com/2021-01-22-Boeing-Commits-to-Deliver-Commercial-Airplanes-Ready-to-Fly-on-100-Sustainable-Fuels

155. The Boeing Company (2020), Commercial market outlook 2020-2039. Retrieved from: https://www.boeing.com/resources/boeingdotcom/market/assets/downloads/2020_CMO_PDF_Download.pdf

156. Turnpenny J., Jones M. and I. Lorenzoni (2011), Where now for post-normal science? A critical review of its development, definition and uses, *Science, Technology & Human Values*, 36(3):287-306.

157. UCS (2020, August 12), Each country's share of CO_2 emissions. Retrieved from: https://www.ucsusa.org/resources/each-countrys-share-co2-emissions

158. van der Sluijs, J.P. (2012), Uncertainty and dissent in climate risk assessment: a post-normal perspective, *Nature and Culture*, 7(2):174-195.

159. van Dyk S., Su J., McMillan J.D. and J. Saddler (2019), Potential synergies of drop-in biofuel production with further co-processing at oil refineries, *Biofuels, bioproducts & biorefining*, 13:760-775.

160. van Dyk S., Saddler J., Boshell F., Saygin D., Salgado A. and A. Seleem (2017), Biofuels for aviation. IRENA Technology brief. Retrieved from: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/IRENA_Biofuels_for_Aviation_2017.pdf

161. van Vuuren D.P., van Vliet J. and E. Stehfest (2009), Future bioenergy potential under various natural constraints, *Energy Policy*, 37(11):4220-4230.

162. Victor D.G., Geels F.W. and S. Sharpe (2019), Accelerating the low carbon transition: the case for stronger, more targeted and coordinated international action, The Brookings Institute. Retrieved from: https://www.brookings.edu/wp-content/uploads/2019/12/Coordinatedactionreport.pdf

163. Vozka P., Vrtiška D., Šimáček P. and G. Kilaz (2019), Impact of alternative fuel blending components on fuel composition and properties in blends with Jet A, *Energy Fuels*, 33(4):3275-3289.

164. WBG (2020), *Air transport annual report 2019*, Washington D.C.: World Bank Group.

165. WEF (2020), Clean Skies for Tomorrow: Sustainable aviation fuels as a pathway to net-zero aviation. Retrieved from: http://www3.weforum.org/docs/WEF_Clean_Skies_Tomorrow_SAF_Analytics_2020.pdf

166. Wormslev E.C., Pedersen J.L., Eriksen C., Bugge R., Skou N., Tang C., Liengaard T., Hansen R.S., Eberhardt J.M., Rasch M.K., Höglund J., Englund R.B., Sandquist J., Güell B.M., Haug J.J.K., Luoma P., Pursula T. and M. Bröckl (2016), Sustainable jet fuel for aviation. Nordic perspectives on the use of advanced sustainable jet fuel for aviation, Norden. Retrieved from: https://www.nordicenergy.org/wp-content/uploads/2016/09/FULLTEXT_Sustainable_Jet_Fuel_for_Aviation.pdf

167. Yang J., Xin Z., He Q., Corscadden K. and H. Niu (2019), An overview on performance characteristics of bio-jet fuels, *Fuel*, 237:916-936.

168. Zheng S. and D. Rutherford (2020), Fuel burn of new commercial jet aircraft: 1960-2019, ICCT White Paper. Retrieved from: https://theicct.org/sites/default/files/publications/Aircraft-fuel-burn-trends-sept2020.pdf

United Nations regulations, documents, resolutions, working papers and information papers

United Nations Framework Convention on Climate Change (UNFCCC)

169. *Kyoto Protocol to the United Nations Framework Convention on Climate Change*, 11 December 1997, Annex. Decision 1/CP.3. FCCC/CP/1997/7/Add.1. 25/03/1998. Retrieved from: https://unfccc.int/resource/docs/cop3/07a01.pdf

170. Methodological issues related to the Kyoto Protocol, Decision 2/CP.3. FCCC/CP/1997/7/Add.1. 25/03/1998. Retrieved from: https://unfccc.int/resource/docs/cop3/07a01.pdf

International Civil Aviation Organization (ICAO)

171. *Convention on International Civil Aviation*, 7 December 1944, 15 UNTS 295, ICAO Doc 7300/06. [*Chicago Convention*]. Retrieved from: https://www.icao.int/publications/Documents/7300_orig.pdf

172. 40th Assembly Resolution A40-19: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), October 2019. Retrieved from: https://www.icao.int/environmental-protection/Documents/Assembly/Resolution_A40-19_CORSIA.pdf

173. 40th Assembly Resolution A40-18: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Climate change, October 2019. Retrieved from: https://www.icao.int/environmental-protection/Documents/Assembly/Resolution_A40-18_Climate_Change.pdf

174. 39th Assembly Resolution A39–3: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Global Market-based Measure (MBM) scheme, October 2016. Retrieved from: https://www.icao.int/environmental-protection/Documents/Resolution_A39_3.pdf

175. 37th Assembly Resolution A37–19: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Climate change, October 2010. Retrieved from: https://www.icao.int/environmental-protection/37thAssembly/A37_Res19_en.pdf

176. 36th Assembly Resolution A36-22: Consolidated statement of continuing ICAO policies and practices related to environmental protection, September 2007. Retrieved from: https://www.icao.int/environmental-protection/Documents/A36_Res22_Prov.pdf

177. Present and future aircraft noise and emissions trends, A39-WP/55 [Presented by the Council of ICAO], 17/06/2016. Retrieved from: https://www.icao.int/Meetings/a39/Documents/WP/wp_055_en.pdf

178. Trends and scenarios on alternative fuels, CAAF/2-WP/06. 07/09/2017. Retrieved from: https://www.icao.int/Meetings/CAAF2/Documents/CAAF.2.WP.006.4.en.pdf

179. Global Framework for Aviation Alternative Fuels, CAAF/09-WP/23. 18/11/2009. Retrieved from: https://www.icao.int/Meetings/caaf2009/Documents/CAAF-09_WP023_en.pdf

European Commission

180. ReFuelEU Aviation – Sustainable Aviation Fuels, IIA-Ares(2020)1725215. 24/03/2020. Retrieved from: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12303-ReFuelEU-Aviation-Sustainable-Aviation-Fuels

ASTM International standards

181. ASTM D1655, 2020d (1959), Standard Specification for Aviation Turbine Fuels, West Conshohocken: ASTM International. Retrieved from: http://www.astm.org

182. ASTM D7566, 2020c (2009), Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons, West Conshohocken: ASTM International. Retrieved from: http://www.astm.org

183. ASTM D4054, 2020c (2009), Standard Practice for Evaluation of New Aviation Turbine Fuels and Fuel Additives, West Conshohocken: ASTM International. Retrieved from: http://www.astm.org

Foreword to chapter 3

The third chapter utilizes Carol Bacchi's *what's the problem represented to be?* (WPR) method of discourse analysis, with the main objective to identify and gain a better understanding of the premises and effects, both symbolic and material, of the problem representations constructed and articulated by the air transport sector concerning its climate impact. The analysis centers on the ICAO's alternative jet fuel strategy; with a secondary objective of challenging the dominant representations in favor of those articulated from a strong sustainability perspective.

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3

“Problematizing” carbon emissions from international aviation and the role of alternative jet fuels in meeting ICAO’s aspirational goals

Abstract

Alternative jet fuels are one of the four mechanisms by the United Nations International Civil Aviation Organization (ICAO) to limit and reduce carbon emissions from international aviation. By using Carol Bacchi's *what's the problem represented to be?* method of discourse analysis, the objective of this paper was to identify and understand the premises and effects of the problem-solving paradigm underlying ICAO’s alternative jet fuel strategy. As a result, three problem representations were identified, from which two out of four underlying assumptions have reinforced ICAO’s weak sustainability approach to international aviation’s growth and have led to a number of discursive, subjectification and lived effects. The selected method also allowed the authors to identify several options to disrupt those premises in favor of the implementation of more aggressive mitigation and adaptation strategies without constraining air travel demand, including: (i) raising awareness of the environmental impacts of aviation beyond the tailpipe emissions, (ii) improving the understanding of the effects of climate change on the air transport sector, and (iii) reassessing the sectoral approach to the Sustainable Development Goals so as to gain consistency with the aims of the UN *2030 Agenda for Sustainable Development*.

Keywords: alternative jet fuels, policy analysis, weak sustainability, international aviation, climate change.

3.1. Introduction

In 2014, the aviation sector contributed with 3.5 percent of the global gross domestic product (GDP), supported 62.7 million direct, indirect, induced and catalytic jobs, and in 2017, transported over 4 billion passengers (ICAO 2018; WEF 2017; ATAG 2016a). Conversely, domestic and international flights currently account for ~2 percent of the total carbon dioxide (CO_2) emissions from anthropogenic origin (IATA 2015; Penner et al. 1999), a contribution that can be as high as 4.9 percent when the radiative forcing effect of greenhouse and non-greenhouse gas emissions at cruise altitude is accounted for (Moore et al. 2017; Novelli 2011; Lee et al. 2009; Penner et al. 1999). Although aviation's contribution to climate change appears to be small, the lower end is comparable to the total greenhouse gas emissions (GHGs) of Germany, ranked within the top ten largest global emitters (FCCC/CP/2015/10).

Whereas the emissions reductions from domestic aviation are governed by the Paris Agreement, emissions from international aviation are addressed by Member States to the United Nations International Civil Aviation Organization (ICAO) through their national Action Plans to operationalize two of the industry's climate targets[1] endorsed in 2010 by ICAO's 37th General Assembly (ICAO 2014; A37-19), consisting of:

I. An average 2% annual improvement in fuel efficiency from 2009 until 2020[2], and
II. Carbon-neutral growth[3] from 2020.

Although these aspirational targets are ambitious, they are insufficient to meet those of the Paris Agreement, as they do not appropriately account for the required carbon reductions to limit global warming to 1.5-2°C. According to Pidcock and Yeo (2016), by 2050 carbon emissions from international aviation will still represent 12% of the 205Gt CO_2 remaining global carbon budget

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[1] The International Air Transport Association (IATA) set a third target consisting of halving CO_2 emissions by 2050 relative to 2005 levels (ATAG 2012).
[2] The original target set in 2009 by IATA was a 1.5 percent annual increase in fuel efficiency (ATAG 2012).
[3] The international aviation community defines carbon-neutral growth as an absolute decoupling of greenhouse gas emissions from economic sectoral growth.

even if technological and operational efficiencies are maximized and the total demand for conventional jet fuel is met with alternatives.

This contribution can rise up to 20% should alternative jet fuels not become available in sufficient quantities to replace the demand for conventional jet fuel in its entirety (Staples et al. 2018; Pidcock and Yeo 2016). In the past, the EU has suggested more aggressive carbon reduction targets for international aviation to be consistent with the 1.5-2°C global aspirational goal, with sectoral reductions needed between 64% to 91% by 2050 compared to 2005 levels (Cames et al. 2015).

By using Carol Bacchi's (2009) *what's the problem represented to be?* (WPR) method of discourse analysis (a detailed description is presented in section 3.3), this chapter aims to contribute to a better understanding of ICAO's strategy on alternative jet fuels (AJF), as they are perceived by the aviation community to hold the greatest potential to meet ICAO's international goals (CAAF/2-SD3; ATAG 2012).

The WPR is a six-step method to examine the premises and effects of the problem-solving paradigm underlying ICAO's work on environmental protection so as to identify its material and symbolic impacts on people and the environment. Most importantly, it is a useful method to challenge current problem representations in favor of policy interventions more consistent with the goals of the Paris Agreement and of the United Nations *2030 Agenda for Sustainable Development*.

3.2. Background

In addition to the aspirational targets adopted in 2010, ICAO's 37th General Assembly endorsed the *Program of Action on International Aviation and Climate Change* to develop a global framework consisting of operational, technological, market-based measures, and the use of alternative fuels to address CO_2 emissions from international aviation (ICAO 2013a).

Emissions from international aviation are calculated based on fuel consumption, thus the proposed framework has aimed at increasing jet fuel savings. Carbon reductions from technological measures include: the use of lighter and recyclable materials, higher engine performance, fleet renewals, compliance with emissions certification standards – including ICAO's aircraft CO_2 standard –, improvements in aircraft aerodynamics, etc. Fuel savings from operational measures include improvements in air traffic flow management, dynamic and flexible routing, airport design and operations, performance-based navigation, etc. (ICAO 2013b).

Whereas the fuel efficiency target has been met over the past years mainly as a result of technological and operational measures (ATAG 2017), ICAO's assessments on fuel consumption and emissions show that the aggregate environmental benefit achieved by a combination of the technological and operational measures will be insufficient to attain carbon-neutral growth from 2020 (A39-WP/55). This, coupled with other factors analyzed later in this paper, make international aviation reliant on the use of alternative jet fuels to achieve greater carbon reductions.

In 2017, there were five certified conversion pathways for alternative jet fuel production under ASTM D7566, four airports regularly distributing AJF and over 100,000 commercial flights[4] that had used alternative fuels. However, regular production of alternative jet fuels remained limited, and volumes supplied through off-take agreements between airlines and fuel producers could amount to 0.9Mt per year (less than 0.006 percent of total jet fuel consumption by international aviation in 2010), making it difficult to predict their future contribution to meeting ICAO's aspirational goals (CAAF/2-WP/06).

In an effort from ICAO to accelerate the development and adoption of alternative jet fuels, Member States convened in Mexico City at the Second Conference on Aviation and Alternative Fuels (CAAF/2) in October 2017 to set short-to-long term volumetric targets for alternative jet fuels. However, no consensus amongst participant States on specific targets was reached, and the Conference endorsed the *2050 ICAO Vision for Sustainable Aviation Fuels* without any quantitative goals for substituting conventional jet fuel nor any quantifiable carbon reductions resulting from the use of alternative jet fuels (CAAF/2-SD3).

[4] https://www.icao.int/environmental-protection/gfaaf/pages/default.aspx on October 24 and November 20, 2017.

Although ICAO's market-based measure was originally envisioned in 2010 as a complementary measure to further the CO_2 reductions achieved through improvements in technology and operations, in October 2016, ICAO's 39th General Assembly approved the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) to address *any annual increase* in the total CO_2 emissions from international aviation that exceed the 2020 baseline (A39-3).

3.3. Understanding policy governance as "problem" representations

Carol Bacchi's (2009) *what's the problem represented to be?* (WPR) methodological approach consists of a six-step method to examine how "problems" are represented in public policy to identify the material and symbolic impacts that problem representations have on the subjects of those policies.

Bacchi's method builds on much of the work by Michel Foucault on discourse analysis, the history of thought and the process by which thoughts are "problematized" or reflected in the form of socially constructed "problems" and addressed in public policy (Foucault 1984). According to Foucault (1984), the nature, scope and type of solutions articulated through public policy will inevitably result from a specific form of "problematization".

To illustrate this point, in his History of Madness[5] (1972), Foucault analyzed the process by which certain behaviors at the end of the 18th Century were characterized and classified as mental illnesses whereas others would be completely neglected, and the way those problematizations affected-the and were affected-by the political practices, ethical attitudes and social regulations at that particular period in time (Foucault 1983).

Bacchi goes beyond the Foucauldian approach by proposing a method that challenges problematizations that have negative effects on policy subjects at the expense of others (Bacchi 2009). Although her original scope is limited to the problem-solving paradigm underlying public policy in Western industrialized nations and international organizations, Bacchi's WPR approach

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[5] Also titled *Madness and civilization: A history of insanity in the age of reason* (1964) as originally translated from its French title *Folie et déraison: Histoire de la folie à l'âge classique* (1961).

is suitable for the analysis of policies in a variety of political regimes and institutions. Also, notwithstanding that it was originally designed and has been applied ever since for public policy analysis, the WPR is equally useful to analyze ICAO's alternative jet fuel strategy, where the novelty of this research paper rests.

The WPR method follows a set of six questions: [Q1] What is the "problem" represented to be in a given policy? [Q2] What assumptions underlie this problem representation? [Q3] How has this representation of the problem come to prominence? [Q4] What does this representation of the problem take for granted and leave unquestioned? [Q5] What effects are produced by this representation? [Q6] How and where is this representation of the problem produced, disseminated and defended? And how could it be challenged?

3.4. Debriefing the *problem-solving* paradigm underlying ICAO's alternative jet fuel strategy

ICAO's alternative jet fuel strategy supports and promotes the development and consolidation of supply chains of alternative fuels for international aviation through its Member States. It was originally developed within ICAO's *Program of Action on International Aviation and Climate Change* and it encompasses a broad range of activities including R&D, certification, financial assistance, monitoring, verification and evaluation (MRV), technology transfer, capacity building, etc. (CAAF/09-WP/24).

The exchange of information, worldwide initiatives, actions and best practices is facilitated by ICAO's Global Framework for Aviation Alternative Fuels (GFAAF), an online platform created in 2009 to help Member States accelerate the development and adoption of alternative jet fuels (CAAF/2-WP/4; CAAF/09-SD/3).

The following figure (Fig.3.1) summarizes the findings for questions Q1-Q5, each of which is analyzed in separate sections. The findings and respective analysis for Q6 are presented later in this chapter (Fig.3.2).

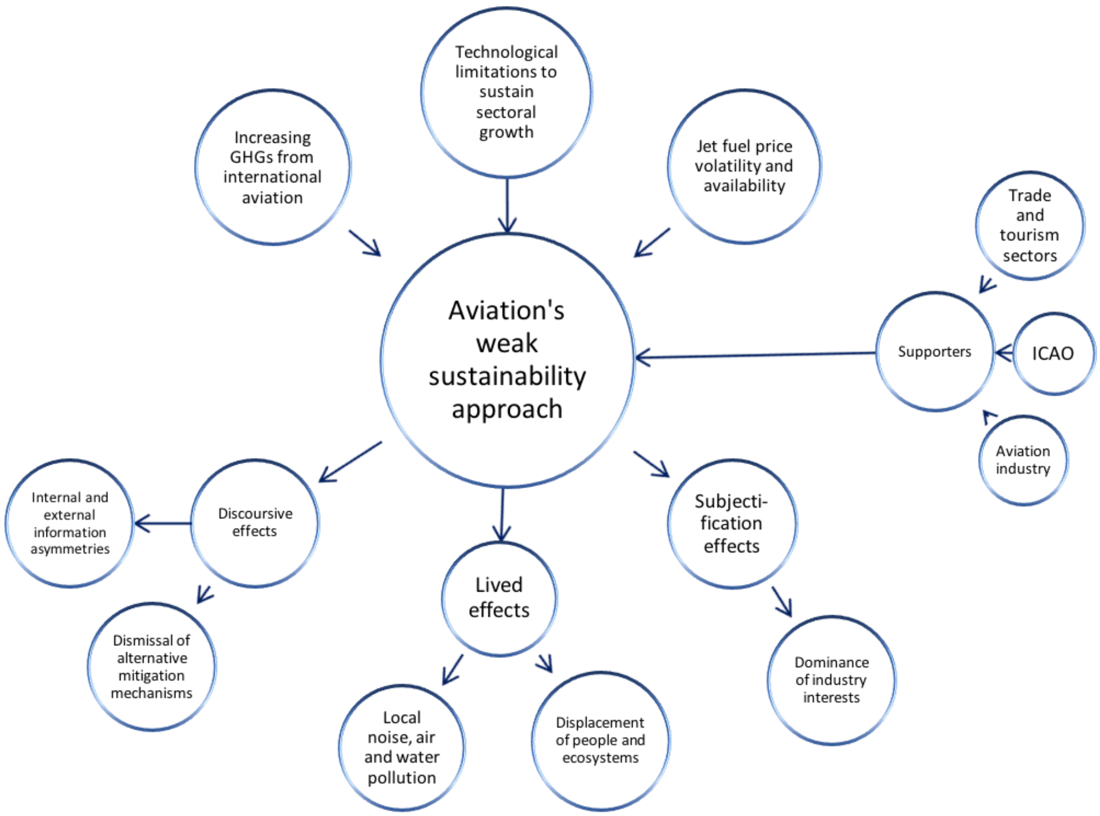

Figure 3.1. Problem representations, premises and effects underlying ICAO's jet fuel strategy

3.4.1. [Q1] What is the "problem" represented to be?

Three problem representations were identified in ICAO's alternative jet fuel strategy: (1) A *main* "problem" represented by the current and future contribution of GHG[6] emissions from international aviation to global warming and climate change (A37-19). (2) A *secondary* "problem" represented in the technological limitations to attain the necessary CO_2 reductions to sustain the five percent annual growth in air traffic projected by the industry (IATA 2015; AEF 2014).

[6] Although ICAO acknowledges the effects of other GHG emissions on global warming and climate change, the aspirational targets explicitly aim at reducing CO_2 emissions as it is released in greater quantities than others and it has a longer atmospheric persistence (A37-19). Furthermore, there are areas of scientific uncertainty about the effects of other emissions (NO_x, SO_x, CH_4, O_3, PM and H_2O) released at cruise altitude (8-13 kilometers AMSL) that have limited the development of a more comprehensive approach from ICAO to mitigation (Moore et al. 2017; Novelli 2011; Lee et al. 2009; Penner et al. 1999; Piera 2015).

The secondary problem is implicit in several ICAO documents where the use of alternative jet fuels aims to close "the mitigation gap" between ICAO's aspirational goals and the carbon reductions attained with conventional fuel savings resulting from the implementation of operational and technological measures (CAAF/09-WP/23).

(3) An *incidental* "problem" represented by the uncertainty around jet fuel price volatility and supply shortages. Although the focus on energy security progressively shifted towards the sustainability of alternative jet fuels as a result of the oil price crash in 2014, ICAO's strategy originally intended to mitigate airlines financial risk by diversifying the fuel market (CAAF/09-WP/23; Palmer 2015).

3.4.2. [Q2] What assumptions underlie these problem representations?

There are two assumptions underlying the *main* problem representation: the first one is that anthropogenic emissions from aviation cause interference with the climate system by contributing to the greenhouse gas effect (Penner et al. 1999). The second assumption is the incontestability of international aviation's growth as sine qua non to support "global social and economic development and inclusion" (ATAG 2016a); a governing principle in ICAO's work as delegated by the *Convention on International Civil Aviation* (*Chicago Convention* 1944).

The assumption underlying the *secondary* problem representation is the nature of carbon emissions from aviation as strictly a technological problem that should, in consequence, be addressed through technological and market-based solutions. Last, the assumption underlying the *incidental* problem representation is the need to diversify international aviation's fuel portfolio in face of an uncertain future of finite fossil resources, as world production from conventional oilfields has been slowly but steadily declining since 2005, and the oil industry faces steeper production costs for lower resource quality and a slower supply growth (Heinberg 2014).

3.4.3. [Q3] How have these problem representations come to prominence?

All three problem representations have similar roots in the context of an increasing awareness of resource scarcity and the global ecological crisis. The acknowledgement of the increasing contribution of international aviation to climate change (*main* problem representation) came about as the result of ICAO's progressive involvement in addressing the environmental impacts of air transport since the 1960s (Pelsser 2017; Piera 2015).

But according to Piera (2015), ICAO's engagement in climate change discussions was mainly brought about by "the possibility that the United Nations Framework Convention on Climate Change (UNFCCC) [could] take over the regulation of GHGs emissions from international aviation and the threat posed by unilateral EU action" by incorporating foreign aircraft operators into the European Union's Emissions Trading Scheme (ETS). Also, several international organizations and non-governmental organizations have strongly criticized ICAO's lack of progress on climate mitigation in the past couple of decades, and have suggested to penalize international aviation by imposing financial sanctions to generate revenue for climate mitigation and adaptation in developing countries (Piera 2015; Palmer 2015).

The recognition of the technological limitations to attain carbon-neutral growth of international aviation (*secondary* problem representation) arose as a result of the increasingly marginal fuel efficiency gains in the last couple of decades. Historic trends claim that aircraft are presently 80% more fuel efficient than they were in the 1960s (ATAG 2010), and although the average annual efficiency improvement of 2.4% between 2009 to 2014 exceeded ICAO's 2% target (ATAG 2016b), aircraft manufacturers acknowledge that cumulative efficiency gains will not be enough to halve international aviation emissions by 2050 alone (Epstein 2017).

The uncertainty around jet fuel price volatility and supply shortages (*incidental* problem representation) first became prominent with the Organization of the Petroleum Exporting Countries (OPEC) embargo of 1973 and the economic recession that followed it (Du Pisani 2006). Yet, the international aviation industry has continued to grow since the post-WWII era in spite of the oil peak prices triggered by the Iranian Revolution (1978), the Iran-Iraq War (1980), the first Persian Gulf War (1990) and the oil price spike of 2007-2008 (Hamilton 2011).

On this, a study by Kasarda (2010) showed a positive correlation between jet fuel prices and the number of passengers and cargo between 1987 and 2008, and found no evidence that oil peak prices had curbed international aviation's growth. According to Lee et al. (2009), this was also the case for major geopolitical events such as the terrorist attack of 9/11, the severe acute respiratory syndrome (SARS) epidemic of 2003, and the global financial crisis of 2008, where the international passenger traffic between 2000 to 2007 increased by 38% as a result of an average annual traffic growth rate of 5.3%.

Notwithstanding the dynamism and adaptation capacity of international aviation to price shocks and global crises, global efforts to adopt alternative energy sources remain driven by the potential threat of conventional fuel price volatility and supply shortages (ATAG 2017; ICAO 2012).

Coincidentally, the idea of using alternative fuels to replace conventional jet fuel gained momentum around the years of the oil price spike of 2007-2008, when several test flights demonstrated the use of alternative fuels as convenient and safe replacements of fossil fuel (CAAF/09-WP/23; ASTM D7566; IATA 2009). Preference for alternative jet fuels was reinforced overtime by the following factors:

First, the current technological barriers to power aircraft with cleaner energy carriers make air transport reliant exclusively on liquid fuels. Second, even if a technological breakthrough would become commercially available before 2050, new technological developments in the aviation sector usually take up to a couple of decades before reaching maturity (IATA 2013). Third, aircrafts in service can only be phased-out gradually as they reach the end of their service life, which is estimated between 20 to 25 years on average (Jiang 2013).

3.4.4. [Q4] What do these problem representations take for granted and leave unquestioned?

All three problem representations leave unquestioned the notion of *progress*, a key concept that historically preceded those of *sustainability*, *development*, and *sustainable development* (Du Pisani 2006), and that underlies the sectoral approach of international air transport. Whereas an in-depth discussion about the history and development of the concept of sustainable development goes beyond the purpose of this paper and prolific scholarly discussions can be found elsewhere (Munda 2008; Du Pisani 2006; Luke 2005; Redclift 2005), it is nonetheless essential to clarify the epistemological principles underpinning the mitigation strategies of the international air transport sector in order to gain a better understanding of their material and symbolic impacts on society and the environment.

The *Chicago Convention* (1944) was drafted close to the end of WWII, preceding by nearly two decades the environmental movements that gave birth to the notion of sustainable development. The original text mandated ICAO to guarantee the "safe, regular, efficient and economical" development of air transport to "meet the needs of the peoples of the world" (Article 44d), and at the time it was drafted it did not contain any provisions related to the environment.

With the unprecedented economic thriving of the 1950s and over the course of the second half of the 20th century, lower air transport fares prompted a considerable growth in demand for air travel services, which had become more accessible as a result of higher disposable incomes and the progressive economic liberalization that enhanced global market access and trade (WEF 2017; ATAG 2016a; Piera 2015; Macintosh and Wallace 2009). From 1960 to 1997, passenger traffic grew at an annual rate of 9 percent, and since the 1980s, air traffic has doubled every 15 years, reaching 4.1 billion people in 2017 and expecting to reach 7.8 billon by 2036 (ICAO 2018; Airbus 2017; IATA 2017).

ICAO's regulations on environmental protection were incorporated to the *Chicago Convention* in 1971 under Annex 16 *Environmental Protection* (Pelsser 2017), and since then, ICAO has increasingly allocated financial resources to *minimize* the adverse environmental effects of civil aviation activities as stated in the organization's Strategic Objectives (2017) (Piera 2015). However, there is no specific reference to the principle of "environmental protection" in ICAO's constitutional framework and governing structure, leading to an understanding of *progress* that legitimizes and promotes the expansion of international aviation in pursuance to the original mandates of the *Chicago Convention*.

This understanding of *progress* is rooted in the positivist thinking of the 18th and 19th centuries that linked the idea of human advancement and well-being to the economic and material growth brought about by the Industrial Revolution (Du Pisani 2006; Von Wright 1997; Nisbet 1980). The neoliberal approach to sustainable development builds on this notion of progress, where environmental degradation and social inequality are considered market externalities (Du Pisani 2006; Luke 2005; Redclift 2005; Euractiv 2002) and where economic growth justifies the replacement of natural capital for human capital, the latter amounting to the concept of *weak* sustainability (Munda 2008; Du Pisani 2006).

Ever since the Rio Declaration (*Agenda 21*) in 1992, the weak sustainability approach has underpinned the work of governments and international organizations alike (Redclift 2005) and has provided them with the legitimacy to mobilize around policies that advocate for mass consumption (Du Pisani 2006). Particularly, the weak sustainability approach underlying ICAO's work on environmental protection, including its alternative jet fuel strategy, was reinforced in 2015 with the endorsement of the United Nations Sustainable Development Goals (SDGs), a global framework consisting of 17 overarching goals and 169 targets over the next 15 years to end poverty, protect the planet and ensure world peace and prosperity (A/RES/70/1). Both ICAO and the aviation industry have asserted that the international air transport *significantly* contributes to 15 out of the 17 SDGs (A39-WP/374; ATAG 2017 and 2016a), and have urged governments worldwide to prioritize and encourage the development of aviation as a driver for sustainable development (A39-WP/25).

Whereas external restrictions for further sectoral expansion have been warned by ICAO to be detrimental to the attainment of the SDGs and for the advancement of humankind (A39-WP/374), advocates of a *strong* sustainability approach (natural capital and human capital are not interchangeable (Munda 2008)) have remarked the role of international aviation in undermining the realization of sustainable development as a whole should unrestrained sectoral growth be encouraged and sustained (A39-WP/427; WWF and Care Intl. 2016).

3.4.5. [Q5] What effects are produced by these problem representations?

The symbolic and material impacts of a public policy can be positive and negative, and the WPR classifies them into discursive, subjectifying and lived effects. The discursive effects result from the limits imposed on what can be said or thought; the subjectification effects involve how subjects are constituted within problem representations, and the lived effects consist of the material impacts of those representations on people and the environment (Bacchi 2009).

This section focuses only on the negative effects of ICAO's alternative jet fuel strategy because the objective of the WPR is to scrutinize and clarify a policy's problem representations and their underlying assumptions so as to identify potential interventions to reduce or eliminate those effects (Bacchi 2009). Also, whereas the benefits of air travel have been widely documented by ICAO, the industry and other sectors highly reliant on the air transport sector (WEF 2017; ATAG 2016a; ICAO 2012), most of its negative effects have currently no visibility.

3.4.5.1 Q5 Discursive effects

The assumptions underpinning the foregoing problem representations have encouraged ICAO and the industry to historically underplay the sector's environmental impacts while overemphasizing the social and economic benefits brought about by aviation (Piera 2015; Ghosh 2014; Bridger 2013; Shaw and Thomas 2006). This has led to a number of discursive repercussions:

First, it creates information asymmetries between air transport service providers (i.e. airlines and airports), and users – including cargo –, who *experience* the advantages of aviation but remain largely unaware of its environmental impacts (Ghosh 2014; Bridger 2013; Shaw and Thomas 2006). Second, it creates information asymmetries between ICAO and its Member States that have resulted in a generalized understating of the urgency to implement more ambitious mitigation and adaptation strategies through their State Action Plans (Piera 2015).

Third, ICAO's definition of environmental impacts as technological in essence, rejects mitigation approaches that could contravene the aims of the *Chicago Convention*. For example: regulations to constraint demand for air transport services, carbon-pricing mechanisms such as levies on conventional jet fuel and on carbon emissions, restrictions on airport expansion projects, etc. (Piera 2015; Bridger 2013; Macintosh and Wallace 2009).

3.4.5.2 Q5 Subjectification effects

The subjectification effect created by ICAO's alternative jet fuel strategy is not exclusive to it and can be generally identified in ICAO's policies on environmental protection. By promoting sectoral growth while addressing environmental issues through technology, ICAO has recurrently placed the interests of the aviation industry ahead of the environment, of the needs from its Member States that are the most vulnerable to climate change and from those that do not hold membership in the Council and the Committee on Aviation Environmental Protection (CAEP).

Whereas ICAO's *weak* approach to sustainable development has resulted in great exogenous and endogenous pressure in the last couple of decades to reduce the environmental impacts of international aviation (Palmer 2015; Piera 2015; ICAO 2012), the prominence of the industry could drive more ambitious climate goals. As Piera (2015) has remarked, the role of the International Air Transport Association (IATA) was instrumental in ICAO's adoption of the aspirational targets to reduce the sectoral carbon emissions, and in the agreement and development of CORSIA.

3.4.5.3 Q5 Lived effects

Much of the research conducted since the 1960s on the impacts of aviation have widely covered the most prominent lived effects, particularly its contributions to global warming, to noise and to local air pollution. Less visible lived effects from ICAO's weak sustainability approach include: water contamination from de-icing operations and fuel leaks and spills, the displacement of vulnerable groups entailed by the expansion of airport infrastructure, the loss of wildlife and ecosystems damage, and the spread of invasive species (Bridger 2013; Kolmes 2011).

The great expectations placed by ICAO and the industry on the use of alternative jet fuels to meet the aspirational targets are not exempt from additional lived risks, particularly from emerging bioenergy crops and large-scale production. For example, the preference of dedicated bioenergy feedstocks over edible and non-edible agronomic crops does not eliminate the issues of land use, as they can also displace forests, grazing land and directly compete with agricultural land for food production (Rude et al. 2017; Mondou and Bognar 2017). Furthermore, certain traits that make emerging bioenergy feedstocks desirable for alternative fuels production, are also found in invasive plants that could spread through a variety of vectors such as the movement of equipment and goods, livestock, packaging, regional and international trade and tourism, and natural events such as floods and winds (IUCN 2009; Crosti 2009).

In consequence, large-scale production of alternative jet fuels could aggravate the direct and indirect environmental impacts linked to intensive agriculture of dedicated bioenergy feedstocks (Novelli 2011; Giampietro and Mayumi 2009), result in an absolute increase of carbon emissions from international aviation (Staples et al. 2018), and reduce the potential social spillovers from small-to-medium farming operations.

3.4.6. [Q6] How and where are these problem representations produced, disseminated and defended? And how can they be questioned, disrupted and replaced?

ICAO and the industry are not the only stakeholders to have historically understated the sector's environmental impacts while overemphasizing its social and economic benefits. This discourse has also been endorsed, disseminated and defended by international organizations that represent the interests of the trade and tourism sectors, including UN World Trade Organization, the World Economic Forum, and the World Travel & Tourism Council (WEF 2017; Becken 2006).

Conversely, factions within the European Union and the non-governmental organizations (NGOs) that conform the International Coalition for Sustainable Aviation (ICSA) have for a few decades challenged ICAO's weak sustainability approach and continue to strongly advocate for more aggressive policies and regulations to address the environmental impacts of international aviation (Girling 2017; A39-WP/427).

Although the narrative of ICAO and the industry has not changed much since the adoption of the Paris Agreement and the Sustainable Development Goals in 2015, the increasing global awareness around aviation's future contribution to climate change, the technological limitations to compensate for the progressive sectoral growth, and the reduced availability of sustainable alternative fuels at present, have all prompted a shift in the discourse of international organizations such as the OECD International Transport Forum (ITF) towards more ambitious carbon reduction strategies (ITF 2017).

In its Transport Outlook 2017, the ITF encourages developed and developing countries to support R&D in conjunction to the implementation of "*avoid* (travel) and *shift* (mode)" policies to influence demand through behavioural change (ITF 2017). At the moment, *avoid* and *shift* policies have mainly been applied to road transport as part of the Nationally Determined Contributions (NDCs) submitted by Member States to the United Nations Framework Convention on Climate Change (UNFCCC) to operationalize the goals of the Paris Agreement, but they are expected to include air transport as they gain momentum amongst policy-makers globally (ITF 2017).

Further disruptions to the current problem representations can be encouraged through several measures. For example, Piera (2015) has suggested regulatory amendments to the *Chicago Convention* and the adoption of pragmatic strategies to increasingly engage developing, least developed countries and more NGOs in ICAO's environmental protection deliberations and negotiations.

Also, public awareness, international discussions and future mitigation and adaptation efforts would greatly benefit from incorporating alternative approaches to the current understanding of ICAO's problem representations (Fig.3.2).

The first approach consists of incorporating the full life-cycle analysis of air transport infrastructure and supply chains (manufacturing, operation, maintenance, etc.) into the environmental impact assessment of international aviation, which according to a study from Chester and Horvath (2009), contribute with at least an additional 31% to the tailpipe emissions from jet fuel combustion. This would provide a more comprehensive understanding of the carbon contributions of international aviation to climate change beyond the "two percent" tailpipe emissions from flight, and a better chance to effectively mitigate the environmental impacts of air transport.

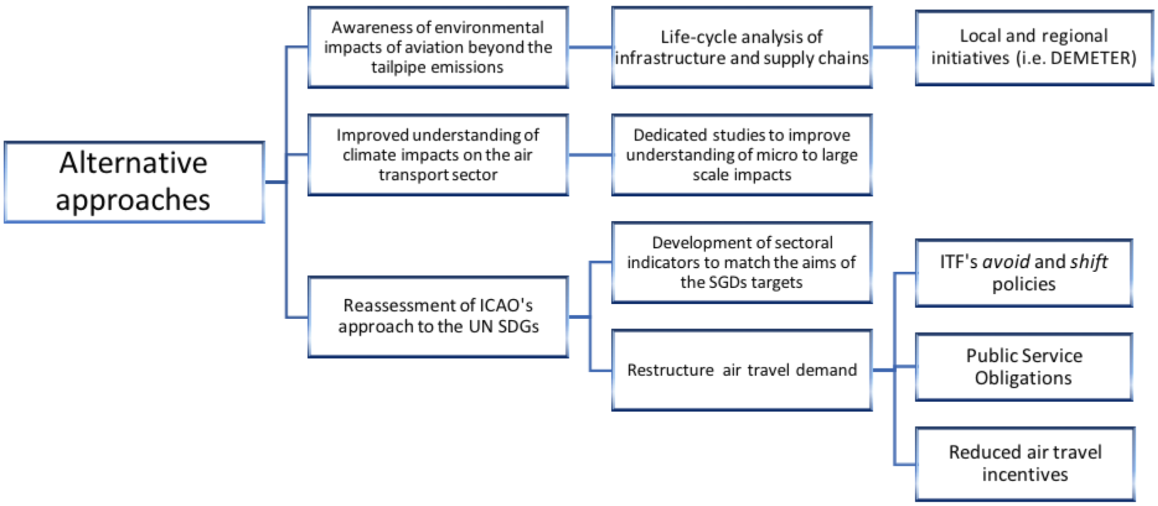

Figure 3.2. Alternative approaches to ICAO's work on environmental protection

For example, project DEMETER (Démonstrateur des Engagements Territoriaux pour la Réduction des émissions) was launched in October 2017 as the first of its kind to address the individual and collective environmental impacts of air transport operations throughout the supply chain around the airport of Toulouse-Blagnac, in France (Eychenne 2017; Bousquet 2017).

The second approach includes raising awareness and improving the understanding of the current and future impacts of climate change on aviation within ICAO, its Member States, the aviation industry and the public in general. Although not yet fully understood, higher air temperatures and sea-level rise are expected to increase airlines and airports' operating costs and the risk of incurring in liabilities as a result of more severe and recurring disruptions on the ground and during flight (Haines 2017; Morad 2017; WMO 2016; Wienert 2010). For example, higher air temperatures affect take-off performance, the usability of short-runways at airports, the recurrence of clear-air turbulence (CAT), and even a flight's length (Karnauskas et al. 2015). Sea-level rise can damage airports, increase the recurrence of runway flooding, prompt flight delays and cancellations due to extreme weather events, and increase the frequency of icing during the fall and winter (Haines 2017; Morad 2017; WMO 2016; Wienert 2010).

Furthermore, climate change could significantly exacerbate the environmental impacts of aviation. To illustrate this point, Karnauskas et al. (2015) found a positive correlation between return journey times of long-haul flights and an increase in the variation of the atmospheric mid-latitude jet stream, suggesting that:

> "For an average change in total round-trip flying time by route (*T*) of one minute, commercial [aircraft] would be in the air ~300,000 h longer per year, amounting to ~1 billion additional gal jet fuel (~US$3 billion fuel cost) and 10,000 million kg CO_2 emitted per year. Such and additional CO_2 emission is equivalent to 1.5% of [the total] CO_2 emissions [from commercial aviation worldwide]" (Karnauskas et al. 2015:1071).

The third approach involves the reassessment of the international aviation's contributions to the SDGs. Whereas ICAO and the aviation industry have asserted the *significant* contributions of air transport to 15 out of the 17 SDGs (A39-WP/374; ATAG 2017 and 2016a), members of the European Union and ICSA have remarked the need for greater consistency in ICAO's work to address climate change in support of the aims of the UN *2030 Agenda for Sustainable Development* (A39-WP/427).

But greater consistency will require reorienting some of ICAO's climate efforts. For example, SDG.12 on responsible consumption and production has been mainly approached by the aviation sector from a technological perspective (i.e. waste reduction and treatment throughout the supply chain, reductions in the energy and material intensity of aircraft manufacturing, material recycling and responsible disposal of aircraft components at their end-of-life, etc.) (Boeing 2017; ATAG 2017; Bombardier 2016). But as it has been remarked by others in the past (A39-WP/427; Palmer 2015; Piera 2015; Bridger 2013) technological efficiencies introduced over the years would have taken place regardless of the sector's climate commitments and as a result of cost-reduction strategies and compliance with local regulations.

SDG.12 is particularly relevant to the aviation sector because it emphasizes the need for governments, international organizations and the private sector to raise public awareness on sustainable development and to encourage the adoption of "lifestyles [that are] in harmony with nature" (SDG.12.8). Also, SDG.12 urges governments to adopt regulatory and policy measures to phase-out fossil-fuel subsidies so as to reduce the environmental externalities of wasteful consumption (SDG.12.8.c) (A/RES/70/1). However, there are no initiatives from ICAO, its Member States or the industry to address these targets and they are not mentioned in their official reports (ATAG 2017; ICAO 2016; A39-WP/374).

While the implementation of "*avoid* (travel) and *shift* (mode)" policies at the national level gains global momentum and terrain (ITF 2017), reorienting ICAO's climate efforts could focus on restructuring air travel demand. One way to do this is by deflecting highly saturated air transport routes to expand the coverage of public service obligation (PSO) routes so as to provide air transport services to communities that would otherwise not be served commercially (Smyth et al. 2012). Within the context of the SDGs, doing so could play a significant role in contributing to the targets of SDG.8 (sustained, inclusive and sustainable economic growth, full and productive employment) and SGD.10 (reduced inequalities within and among countries), as documented by Smyth et al. (2012) apropos of the implementation of the Route Development Fund (RDF) in Scotland.

Member States could also contribute to SDG.12.8 by progressively reshaping air transport demand through the regulation of frequent flyers' programs and by framing frequent travel as a policy issue so as to reduce the economic and psychological incentives to fly (Cohen et al. 2011).

3.5. Conclusions

This research paper aimed at improving the understanding of ICAO's alternative jet fuel strategy by using Carol Bacchi's (2009) *what's the problem represented to be?* (WPR) methodological framework to analyze the premises and effects of the problem-solving paradigm underlying ICAO's work on environmental protection. In consequence, some of the findings of this exploratory exercise could be equally applied to the analysis of ICAO's market-based CORSIA insofar as they both build on the same problem representations and their underlying assumptions (Q1,2). However, a separate analysis would be required for an in-depth understanding of the rationale and the material and symbolic impacts of CORSIA as an indirect carbon mitigation strategy.

Three problem representations were identified in ICAO's alternative jet fuel strategy: (1) the increasing contribution of international aviation to climate change, (2) the technological limitations to constraint and reduce the necessary carbon emissions to sustain the continued sectoral expansion, and (3) the uncertainty around future jet fuel prices and availability. However, two out of the four assumptions underlying the foregoing problem representations have encouraged ICAO and the industry to historically underplay the sector's environmental impacts, leading to a number of discursive, subjectification and lived effects. The first conflicting assumption is that air transport growth is considered by ICAO and the industry as a condition sine qua non for social inclusion and economic development, while the second one is that the environmental impacts from aviation are regarded as strictly technological issues that should be addressed through technological and market-based solutions.

Whereas the social and economic benefits brought about by aviation in the course of over a century are undeniable, the adoption of the Paris Agreement in 2015 and the approval of CORSIA in 2016 have intensified the external and internal pressure on ICAO towards the implementation of more aggressive carbon reduction strategies, some of which challenge the foundational assumptions of the problem representations analyzed in this paper. Also, climate efforts could greatly benefit from incorporating aspects into the international discussions that have received little to no attention, such as: (1) raising awareness of the environmental impacts of aviation beyond the tailpipe emissions, (2) improving the understanding of current and future climate impacts on the air transport sector, and (3) reassessing the sectoral approach to the SDGs so as to gain consistency with the aims of the UN *2030 Agenda for Sustainable Development*.

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Declaration of interest

None.

Literature cited

1. AEF (2014, August 8), "Demand for air travel will have to be limited to meet industry CO_2 targets". Retrieved from: https://www.aef.org.uk/2014/08/08/demand-for-air-travel-will-have-to-be-limited-to-meet-industry-co2-targets/

2. Airbus (2017), Growing horizons: global market forecast 2017-2036. Retrieved from: http://www.airbus.com/content/dam/corporate-topics/publications/backgrounders/Airbus_Global_Market_Forecast_2017-2036_Growing_Horizons_full_book.pdf

3. ATAG (2017), Flying in formation. Retrieved from: http://www.atag.org/component/downloads/downloads/355.html

4. ATAG (2016a), Aviation: benefits beyond borders. Retrieved from: http://www.atag.org/component/downloads/downloads/346.html

5. ATAG (2016b), Fact sheet: delivering fuel efficiency: Retrieved from: http://www.atag.org/component/downloads/downloads/297.html

6. ATAG (2012), Powering the future of flight: The six easy steps to growing a viable aviation biofuels industry. Retrieved from: http://www.atag.org/component/downloads/downloads/152.html

7. ATAG (2010), Beginner's guide to aviation efficiency. Retrieved from: http://www.atag.org/component/downloads/downloads/59.html

8. Bacchi C.L. (2009), *Analysing policy: What's the problem represented to be?*, Frenchs Forest: Pearson.

9. Becken, Susanne (2006), Tourism and transport: the sustainability dilemma, *Journal of Sustainable Tourism*, 14(2):113-116.

10. Bombardier (2016), CS100 Environmental Product Declaration. Retrieved from: http://gryphon.environdec.com/data/files/6/12107/epd921_Bombardier_C_SERIES100.pdf

11. Bousquet, Gil (2017, October 5), "Un 'pack' autour de l'aéroport pour réduire l'effet de serre", La Dépêche. Retrieved from: https://www.ladepeche.fr/article/2017/10/05/2659260-pack-autour-aeroport-reduire-effet-serre.html

12. Bridger, Rose (2013), *Plane truth: aviation's real impact on people and the environment*, London: Pluto Press.

13. Cames M., Graichen J., Siemons A. and V. Cook (2015), Emission reduction targets for international aviation and shipping, report prepared for the European Parliament's Directorate General for International Policies, IP/A/ENVI/2015-11, Brussels. Retrieved

from: http://www.europarl.europa.eu/RegData/etudes/STUD/2015/569964/IPOL_STU(2015)569964_EN.pdf

14. Chester Mikhail V. and Arpad Horvath (2009), Environmental assessment of passenger transportation should include infrastructure and supply chains, *Environmental Research Letters*, 4(2):1-8.

15. Cohen S.A., Higham J.E.S. and C.T. Cavaliere (2011), Binge flying: behavioural addiction and climate change, *Annals of Tourism Research*, 38(3):1070-1089.

16. Crosti, Roberto (2009), Invasiveness of biofuel crops and potential harm to natural habitats and native species, report prepared for the Convention on the Conservation of European Wildlife and Natural Habitats of the Council of Europe. Retrieved from: http://www.globalbioenergy.org/uploads/media/1012_CE_-_Invasiveness_of_biofuel_crops_and_potential_harm_to_natural_habitats_and_native_species.pdf

17. Du Pisani, Jacobus A. (2006), Sustainable development: historical roots of the concept, *Environmental Sciences*, 3(2):83-96.

18. Epstein, Alan (2017, October 4), Session 3: Meeting the 2050 goal to reduce net aviation CO_2 emissions through technology. *ATAG Global Sustainable Aviation Summit*, October 3-4, Geneva.

19. Euractiv (2002, August 19), “Sustainable Development: introduction”. Retrieved from: http://www.euractiv.com/section/sustainable-dev/linksdossier/sustainable-development-introduction-archived/

20. Eychenne, Frederic (2017, November 17), Session 4: Global and regional initiatives. *IATA Alternative Fuel Symposium*, November 16-17, Vancouver.

21. Foucault, Michel (1984), Polemics, Politics and Problematizations, in Paul Rabinow (ed.)(1998), *Essential Works of Foucault*, Vol. 1 “Ethics”, New York: The New Press. Retrieved from: https://foucault.info/doc/foucault/interview-html

22. Foucault, Michel (1983), “Concluding remarks to the seminar”, in Joseph Pearson (ed.) (1999), *Discourse and Truth: the Problematization of Parrhesia*, Seminar given at the University of California at Berkeley in October and November 1983. Retrieved from: https://foucault.info/doc/documents/parrhesia/foucault-dt6-conclusion-en-html

23. Giampietro M. and K. Mayumi (2009), *The biofuel delusion: the fallacy of large-scale agro-biofuel production*, London: Earthscan.

24. Girling, Julie (2017, October 4), Session 4: The big picture and future challenges. *ATAG Global Sustainable Aviation Summit*, October 3-4, Geneva.

25. Ghosh, Arup (2014), Plane truth: aviation's real impact on people and the environment [book review], *International Journal of Environmental Studies*, 71(6):888-898.

26. Haines, Gavin (2017, October 4), "More turbulence and longer runways: seven ways climate change will affect air travel", *The Telegraph*. Retrieved from: http://www.telegraph.co.uk/travel/news/ways-climate-change-could-affect-flying/

27. Hamilton, James D. (2011), Historical oil shocks, NBER Working Paper 16790, Cambridge. Retrieved from: http://www.nber.org/papers/w16790.pdf

28. Heinberg, Richard (2014, December 19), "The oil price crash of 2014", Post Carbon Institute. Retreived from: http://www.postcarbon.org/the-oil-price-crash-of-2014/

29. IATA (2017, October 24), "2036 forecast reveals air passengers will nearly double to 7.8 billion", Press release no.55. Retrieved from: http://www.iata.org/pressroom/pr/Pages/2017-10-24-01.aspx

30. IATA (2015), Sustainable Aviation Fuel Roadmap. Retrieved from: https://www.iata.org/whatwedo/environment/Documents/safr-1-2015.pdf

31. IATA (2013), Technology Roadmap (4th ed.). Retrieved from: https://www.iata.org/whatwedo/environment/Documents/technology-roadmap-2013.pdf

32. IATA (2009, December 8), "Halving emissions by 2050: aviation brings its targets to Copenhagen", Press release no.54. Retrieved from: http://www.iata.org/pressroom/pr/Pages/2009-12-08-01.aspx

33. ICAO (2018, January 17), "Continued passenger traffic growth and robust air cargo demand in 2017". Retrieved from: http://www.unitingaviation.com/strategic-objective/economic-development/continued-passenger-traffic-growth-robust-air-cargo-demand-2017/

34. ICAO (2016), Environmental Report: On board a sustainable future. Retrieved from: https://www.icao.int/environmental-protection/Documents/ICAO%20Environmental%20Report%202016.pdf

35. ICAO (2014), Overview of alternative jet fuels in 2014, published in IATA, *Report on alternative fuels*. Retrieved from: https://www.icao.int/environmental-protection/GFAAF/Documents/Overview%20of%20Alternative%20Jet%20Fuels%20in%202014.pdf

36. ICAO (2013a), Destination Green: driving progress through action on aviation and the environment, *The ICAO Journal*, 68(2). Retrieved from: https://www.icao.int/publications/journalsreports/2013/6802_en.pdf

37. ICAO (2013b), Basket of measures to reduce aviation CO_2 emissions: progress since the 37th Session of the ICAO Assembly. Retrieved from:

http://cfapp.icao.int/tools/38thAssyiKit/story_content/external_files/Flyer_US-Letter_ENV_Basket-Measures_2013-08-28.pdf

38. ICAO (2012), Global aviation and our sustainable future. Retrieved from: https://www.icao.int/environmental-protection/Documents/Rio+20_booklet.pdf

39. ITF (2017), *ITF Transport Outlook 2017*, Paris: OECD Publishing.

40. IUCN (2009), Guidelines on Biofuels and Invasive Species. Retrieved from: https://cmsdata.iucn.org/downloads/iucn_guidelines_on_biofuels_and_invasive_species_.pdf

41. Jiang, Helen (2013), "Key findings on airplane economic life", The Boeing Company. Retrieved from: http://www.boeing.com/assets/pdf/commercial/aircraft_economic_life_whitepaper.pdf

42. Karnauskas K.B., Donnelly J.P., Barkley H.C. and J.E. Martin (2015), Coupling between air travel and climate, *Nature Climate Change*, 5(12):1068-1073.

43. Kasarda, John D. (2010, December 22), "Are rising jet fuel prices leading to the end of aviation? Retrieved from: http://aerotropolisconcepts.blogspot.ca/2010/12/are-rising-jet-fuel-prices-leading-to.html

44. Kolmes, Steven A. (2011), Ground-level pollution, invasive species and emergent diseases, in Elizabeth A. Hoppe (ed.), *Ethical issues in aviation*, Burlington: Ashgate, pp.257-265.

45. Lee D.S., Fahey D.W., Forster P.M., Newton P.J., Wit R.C.N., Lim L.L., Owen B. and R. Sausen (2009), Aviation and global climate change in the 21st century, *Atmospheric Environment*, 43:3520-3537.

46. Luke, Timothy W. (2005), Neither sustainable nor development: reconsidering sustainability in development, *Sustainable Development*, 13(4):228-238.

47. Macintosh A. and L. Wallace (2009), International aviation emissions to 2025: can emissions be stabilised without restricting demand?, Energy Policy, 37:264-273.

48. Moore R.H., Thornhill K.L., Weinzierl B., Sauer D., D'Ascoli E., Kim J., Lichtenstern M., Scheibe M., Beaton B., Beyersdorf A.J., Barrick J., Bulzan D., Corr C.A., Crosbie E., Jurkat T., Martin R., Riddick D., Shook M., Slover G., Voigt C., White R., Winstead E., Yasky R., Ziemba L.D., Brown A., Schlager H. & B.E. Anderson (2017), Biofuel blending reduces particle emissions from aircraft engines at cruise conditions, *Nature*, 543:411-415.

49. Mondou M. and J. Bognar (2017), Policy approaches and lessons for biofuel policy in Canada, in BFN, *What role for advanced biofuels in Canada? A Q&A of policy impacts and options*, The BiofuelNet Canada. [Unpublished manuscript]

50. Morad, Azlan (2017, May 19), "Climate change impact on aviation: what you need to know",

New Airport Insider. Retrieved from: https://newairportinsider.com/climate-change-impact-on-aviation/

51. Munda, Giuseppe (2008), *Social Multi-Criteria Evaluation for a sustainable economy*, Barcelona: Springer.

52. Nisbet, Robert (1980), *History of the idea of progress*, New York: Basic Books.

53. Novelli, Philippe (2011), Sustainable Way for Alternative Fuels and Energy in Aviation (SWAFEA), report prepared for the European Commission's Directorate General for Mobility and Transport. Retrieved from: https://www.icao.int/environmental-protection/GFAAF/Documents/SW_WP9_D.9.1%20Final%20report_released%20July2011.pdf

54. Palmer, Walter J. (2015), *Will sustainability fly? Aviation fuel options in a low-carbon world*, New York: Routledge.

55. Pelsser, Albert (2017, August 17), “The Postal History of ICAO: Annex 16. Environmental Protection”. Retrieved from: https://www.icao.int/secretariat/PostalHistory/index.html

56. Penner J.E., Lister D.H., Griggs D.J., Dokken D.J., and M. McFarland (eds.) (1999), *Aviation and the Global Atmosphere: A special report of the Intergovernmental Panel on Climate Change*, UK: Cambridge University Press.

57. Pidcock Roz and Sophie Yeo (2016, August 8), “Analysis: aviation could consume a quarter of 1.5C carbon budget by 2050”. Retrieved from: https://www.carbonbrief.org/aviation-consume-quarter-carbon-budget

58. Piera, Alejandro J. (2015), *Greenhouse gas emissions from international aviation: legal and policy challenges*, The Hague: Eleven International Publishing.

59. Redclift, Michael (2005), Sustainable development (1987-2005): an oxymoron comes of age, *Sustainable Development*, 13(4):212-227.

60. Rude J., Luckert M. and H. Campbell (2017), Advanced biofuels and macro-economic impacts, in BFN, *What role for advanced biofuels in Canada? A Q&A of policy impacts and options*, The BiofuelNet Canada. [Unpublished manuscript]

61. Shaw S. and C. Thomas (2006), Social and cultural dimensions of air travel demand: hyper-mobility in the UK?, *Journal of Sustainable Tourism*, 14(2):209-215.

62. Smyth A., Christodoulou G., Dennis N., Al-Azzawi M. and J. Campbell (2012), Is air transport a necessity for social inclusion and economic development?, *Journal of Air Transport Management*, 22:53-59.

63. Staples M.D., Malina R., Suresh P., Hileman J.I. and S.R.H. Barrett (2018), Aviation CO_2 emissions reductions from the use of alternative jet fuels, *Energy Policy*, 114(C): 342-354.

64. The Boeing Company (2017), Environment Report: build something cleaner. Retrieved from: http://www.boeing.com/resources/boeingdotcom/principles/environment/pdf/2017_environment_report.pdf

65. Von Wright, Georg H. (1997), Progress: fact and fiction, in Burgen A., McLaughlin P. and J. Mittelstrab (eds.), *The idea of progress*, Berlin: Walter de Gruyter, pp.1-18.

66. World Economic Forum (2017), The travel and tourism competitiveness report 2017: paving the way for a more sustainable and inclusive future, Geneva. Retrieved from: https://www.weforum.org/reports/the-travel-tourism-competitiveness-report-2017

67. Wienert, Uwe (2010), Climate change and its possible impact on aviation, *EASA International Air Safety & Climate Change Conference*, September 8-9, Cologne. [PowerPoint slides]. Retrieved from: https://www.easa.europa.eu/conferences/iascc/doc/Workshop%201%20Presentations/Workshop1_DAY%201/2_Wienert_DWD/Aviation%20&%20Climate%20Change300710_TD.pdf

68. WMO (2016), "Climate change impacts on aviation: an interview with Herbert Puempel", World Meteorological Organization Bulletin 65(2). Retrieved from: https://public.wmo.int/en/resources/bulletin/climate-change-impacts-aviation-interview-herbert-puempel

69. WWF & Care International (2016), Twin tracks: developing sustainably and equitably in a carbon-constrained world (3rd ed.). Retrieved from: http://careclimatechange.org/wp-content/uploads/2016/04/CARE-WWF_Twin-Tracks-3rdEdition.pdf

United Nations regulations, documents, resolutions, working papers and information papers

United Nations General Assembly (UN)

70. Transforming our world: the 2030 agenda for sustainable development, A/RES/70/1. 21/10/2015. Retrieved from: http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

United Nations Framework Convention on Climate Change (UNFCCC)

71. Annex I. Information provided in accordance with paragraph 104 of decision 1/CP.21 related to entry into force of the Paris Agreement (Article 21), FCCC/CP/2015/10. Retrieved from: http://unfccc.int/files/paris_agreement/application/pdf/10e.pdf

International Civil Aviation Organization (ICAO)

72. *Convention on International Civil Aviation*, 7 December 1944, 15 UNTS 295, ICAO Doc 7300/06. [*Chicago Convention*]. Retrieved from: https://www.icao.int/publications/Documents/7300_orig.pdf

73. 39th Assembly Resolution A39-3: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Global Market-based Measure (MBM) scheme, October 2016. Retrieved from: https://www.icao.int/environmental-protection/Documents/Resolution_A39_3.pdf

74. 37th Assembly Resolution A37-19: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Climate Change, October 2010. Retrieved from: https://www.icao.int/environmental-protection/37thAssembly/A37_Res19_en.pdf

75. Aviation's contribution towards the United Nations 2030 Agenda for sustainable development, A39-WP/25 [Presented by ICAO], 05/07/2016. Retrieved from: https://www.icao.int/Meetings/a39/Documents/WP/wp_025_en.pdf

76. Present and future aircraft noise and emissions trends, A39-WP/55 [Presented by the Council of ICAO], 17/06/2016. Retrieved from: https://www.icao.int/Meetings/a39/Documents/WP/wp_055_en.pdf

77. Aviation's contribution towards the United Nations 2030 Agenda for sustainable development, A39-WP/374 [Presented by ACI, CANSO, IATA, IBAC and ICCAIA], 06/09/2016. Retrieved from: https://www.icao.int/Meetings/a39/Documents/WP/wp_374_en.pdf

78. ICAO's climate change measures and the sustainable development goals, A39-WP/427 [Information paper presented by ICSA], 14/09/2016. Retrieved from: https://www.icao.int/Meetings/a39/Documents/WP/wp_427_en.pdf

79. Appendix B. Declaration of the Conference on Aviation and Alternative Fuels, CAAF/09-SD/3. 18/11/2009. Retrieved from: https://www.icao.int/Meetings/caaf2009/Documents/CAAF-09_SD003_en.pdf

80. Appendix. Declaration of the Second Conference on Aviation and Alternative Fuels, CAAF/2-SD3. 13/10/2017. Retrieved from: https://www.icao.int/Meetings/CAAF2/Documents/CAAF2%20SD%20day%203.Final.pdf

81. Follow up con CAAF/1 recommendations, CAAF/2-WP/04. 27/07/2017. Retrieved from: https://www.icao.int/Meetings/CAAF2/Documents/CAAF.2.WP.004.1.en.pdf

82. Trends and scenarios on alternative fuels, CAAF/2-WP/06. 07/09/2017. Retrieved from: https://www.icao.int/Meetings/CAAF2/Documents/CAAF.2.WP.006.4.en.pdf

83. Global Framework for Aviation Alternative Fuels, CAAF/09-WP/23. 18/11/2009. Retrieved from: https://www.icao.int/Meetings/caaf2009/Documents/CAAF-09_WP023_en.pdf

84. Declaration and recommendations, CAAF/09-WP/24. 18/11/2009. Retrieved from: https://www.icao.int/Meetings/caaf2009/Documents/CAAF-09_WP024-Rev_en.pdf

85. Strategic Objectives, 2017. Retrieved from: https://www.icao.int/about-icao/Council/Pages/Strategic-Objectives.aspx

86. ICAO Global Framework for Aviation Alternative Fuels GFAAF, 2017. Retrieved from: https://www.icao.int/environmental-protection/GFAAF/Pages/default.aspx

ASTM International standards

87. ASTM D7566, 2016b (2009), *Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons*, West Conshohocken: ASTM International. Retrieved from: http://www.astm.org

Foreword to chapter 4

Building on the findings of the WPR, the fourth chapter combines qualitative and mixed methods to study stakeholder perceptions by identifying and analyzing collective narratives on AJF that have influence on the environmental policy process at the ICAO. Stakeholder viewpoints have been progressively acknowledged in socio-environmental research as the base for understanding *what* matters, *why* does it and *who* says so in decision-making processes, and as paramount to inform and improve environmental governance.

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4

Alternative jet fuels and climate geopolitics: *what*, *why* does it and *who* matters in the environmental policy-making process

Abstract

Annual emissions from commercial aviation are forecast to reach 1,820 $MtCO_2$ by mid-century, where carbon-neutral growth would demand near full substitution of petroleum-based aviation fuels with alternative jet fuels (AJF). However, the lack of dedicated policies and harmonized regulations has been perceived by stakeholders within the air transport community as the major contributor to shortfalls in global production over the past decade (<0.01% of the total aviation fuel demand). This research combines qualitative and mixed methods to study stakeholder perceptions by identifying and analyzing collective narratives on AJF (*what* matters, *why* does it and *who* says so) influencing the policy process at the ICAO. Q-method allowed to identify four metanarratives across participants, three of which have a distinctive weak sustainability approach to international aviation's growth and one that is typically representative of a strong sustainability approach. This method also revealed a common ground of beliefs and understandings among stakeholders that could facilitate the discussion, negotiation and consensus of some of the multidimensional nuances inherent to the metanarratives analyzed. By classifying stakeholders' salience based on their possession of power, legitimacy and urgency as dynamic and relational attributes to the ICAO, the authors suggest options to bring valuable expertise from low-salient and non-stakeholders into the formulation of policies on AJF through a variety of collaborative arrangements with medium and highly salient stakeholders. The role of AJF is further explored within the context of the COVID-19 outbreak, the *flygskam* movement in Europe, and the impending renewal of climate commitments under the Paris Agreement.

Keywords: alternative jet fuels, Q-method, ICAO, stakeholder analysis, COVID-19, flygskam.

4.1. The words behind the numbers

Societies are governed by the narratives embedded in the political practices, ethical attitudes and social regulations that underlie the nature, scope and the type of public policies articulated in a particular period of time. Most post-empiricist methods of policy analysis focus on deconstructing these narratives attributed to individual or collective stakeholders in a policy issue (van Eeten 2017; Durning 1999; Roe 1994). In contrast, the objective of this study is to examine the underlying discourses driving the adoption of policies and regulations on the use of alternative jet fuels[1] (AJF), as a measure to reduce carbon emissions from international aviation.

Alternative jet fuels were approved for use in commercial aviation in 2009 (ASTM D7566-09), followed by a number of test flights and trials by airlines to promote their uptake[2]. Since 2011, over 300,000 flights[3] have used AJF and production capacity is expected to reach 3.5 billion litres per year by 2025, equivalent to 7 MtCO_2 avoided[4] (ATAG 2020a; Boyd 2019). In 2018, approximately 14 million litres of AJF were blended with petroleum-based fuels (ATAG 2018) and in 2019, this figure nearly trebled to 40 million litres, accounting for <0.01% of the global aviation fuel demand for the same year (ATAG 2020b; IATA 2020a).

Before the global outbreak of the SARS-CoV-2[5] or COVID-19 in March of 2020[6], there were 7 airports in Europe and North America regularly supplying AJF blends, over 6 billion litres of fuel in forward-purchase agreements[7] and 7 conversion pathways approved by ASTM International (ASTM D7566-20b). As these pathways reach commercial maturity, the market share of AJF is

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[1] The international aviation community uses the term sustainable aviation fuels (SAF), to refer to drop-in alternative jet fuels (AJF) that are certified by an authoritative body to meet a set of sustainability criteria (ATAG 2017; A39-3; CAAF/2-WP/03). However, the authors consider the term alternative jet fuels to better represent the variety of drop-in substitutes for petroleum-based fuels or conventional aviation fuels (CAF). AJF are produced from biogenic feedstock (e.g. agronomic and lignocellulosic crops and residues, algae, biogas, CO_2 from direct air capture) via thermochemical and biochemical routes. AJF from non-biogenic feedstock sources (e.g. industrial off-gases, unconventional petroleum) are known as lower carbon aviation fuels (LCAF).

[2] https://aviationbenefits.org/environmental-efficiency/climate-action/sustainable-aviation-fuel/the-leading-edge/ on April 13, 2020.

[3] https://aviationbenefits.org/environmental-efficiency/climate-action/sustainable-aviation-fuel on December 6, 2020.

[4] Assuming an 80% CO_2 reduction potential on a lifecycle basis (ATAG 2020a).

[5] The official acronym stands for "severe acute respiratory syndrome coronavirus 2".

[6] The potential impacts of the pandemic on the deployment of AJF are detailed in section 4.5.

[7] *Supra* footnote 3.

forecast to reach a tipping point in the supply/price balance at 2% of the global aviation fuel stock in 2025 (ATAG 2020c).

The scientific literature on the drivers and constraints to streamline alternative jet fuels has centered on three main areas: a) the techno-economic analysis of fuel production (de Jong 2018; Bann et al. 2017; Atsonios et al. 2015; Neuling and Kaltschmitt 2015); b) their lifecycle sustainability (Staples et al. 2018; ACRP 2018; Fortier et al. 2014; Seber et al. 2014; Han et al. 2013), and c) the geopolitical dimensions influencing AJF commercial deployment (de Jong et al. 2018; Filimonau and Högström 2017; Smith et al. 2017; Timmis 2015; Nair and Paulose 2014).

On the last point, the lack of dedicated policies and harmonized regulations for the development and commercialization of AJF, has been perceived within the air transport community – and recurrently cited in the white and grey literature – as the major contributor to shortfalls in global production. (ATAG 2020c; ICAO 2019a; Deane and Pye 2018; Bosch et al. 2017). Presently, the minimum selling price of AJF remains twice and up to 10 times higher than petroleum-derived Jet A/A-1, depending on the feedstock source and fuel conversion pathway used (de Jong 2018; Bann et al. 2017).

Despite the relevance attributed to these factors, few studies have focused on the role and influence of stakeholder perceptions in shaping policies and regulations that are supportive of AJF deployment (Smith et al. 2017; DOE 2017; Filimonau and Högström 2017; Rains et al. 2017; Gazis et al. 2016; Timmis 2015; NARA 2015; Gegg et al. 2015 and 2014). This observation is not minor, as transcending the dominant empiricist and technocratic rationale to acknowledge stakeholder perceptions as the base for understanding *what* matters, *why* does it and *who* says so, is as relevant to the commercial uptake of AJF – if not more – than the actual economies of scale.

To illustrate this point, the mounting pressure on the air transport sector to address its climate impact, over and above the absence of a concerted effort with global reach amongst stakeholders (Lyle 2019; Soria Baledón and Kosoy 2018), have resulted in policies and regulations internationally to abate carbon emissions without necessarily creating the conditions for AJF volumes to reach 2% of the total jet fuel supply by 2025.

This study primarily uses Q-method (detailed in section 4.2.1) to analyze stakeholder viewpoints (*what* matters, *why* does it and *who* says so) on contentious issues at the international level along the environmental, political, economic, technological and social dimensions of alternative jet fuels. Q-method is a mixed quantitative-qualitative tool used in socio-environmental research to empirically investigate social perspectives on issues that directly affect policy-making and environmental governance (Sneegas et al. 2021; Ramlo 2016).

The novelty of this study relies in the combination of qualitative and mixed methods (see Figure 4.1) to analyze subjectivity in a rigorous and more empirical manner than if solely using qualitative ones. This methodological framework allows identifying collective narratives, hereafter referred to as metanarratives (Roe 1994), that are not sensitive to the a priori background knowledge and expectations of the researcher, while avoiding the metanarratives that merely mirror well-established stakeholder groups (van Eeten 2017).

The metanarratives identified using Q-method are useful to recast the intractable aspects of the AJF debate for two reasons: a) to make them amenable to deliberation, analysis and decision-making (Durning 2006; Roe 1994), and b) to unveil the positioning of stakeholders into coalitions with the agency to further new policy agendas (van Eeten 2017; Hajer 1997). Adding to the latter, the study uses R.K. Mitchell's et al. (1997) stakeholder analysis method to examine the likelihood of stakeholders to influence policy-making on AJF, based on their possession of power, legitimacy and urgency as relational attributes to the ICAO.

4.2. Combining mixed and qualitative methods for analyzing subjectivity

Figure 4.1 presents an overview of the methodological design for this study and how each of the three selected methods were applied. A detailed description of each method is provided in the following subsections (4.2.1, 4.2.2, 4.2.3).

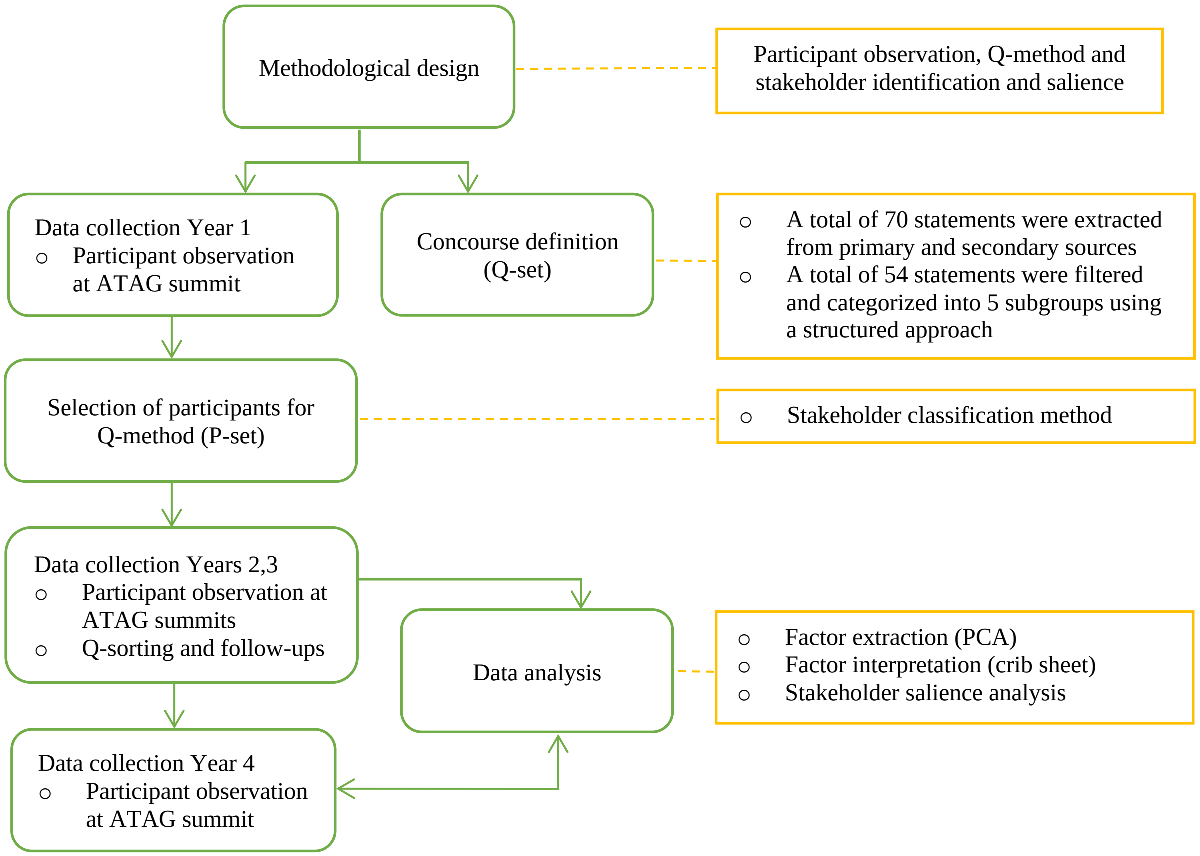

Figure 4.1. Overview of the study design and application

4.2.1. Q-method

Q-method was developed in the 1930s by William Stephenson to provide a scientific foundation, both qualitative and quantitative, to the study of subjectivity. Watts and Stenner (2012) define Q-method as an inversion of Spearman's statistical factor analysis, where commonalities amongst individual viewpoints are systematically identified, studied and explained holistically at a high level of qualitative detail.

This method originally emerged within the field of psychology, and over the past three decades it has quickly spread to a wide range of academic fields, including environmental policy (Watts and Stenner 2012; Addams and Proops 2000; Barry and Proops 1999). But Q-method remains little known within the field of aeronautics; only a handful of studies have been conducted in the last 30 years (Kivits and Charles 2015; Lim 2015; Kroesen and Bröer 2009) since van Eeten (1999) pioneered the field to inform a public enquiry by the Future Dutch Aviation Infrastructure (TNLI), on the construction of a fifth runway at Amsterdam's Schiphol Airport in the mid-1990s.

There are presently no studies of stakeholder perceptions on alternative jet fuels that apply Q-method. Research on this subject has aimed at identifying drivers and barriers for commercial deployment of AJF through commonly used qualitative methods, such as semi-structured interviews (Gazis et al. 2016; Timmis 2015; Gegg et al. 2015 and 2014), in-depth interviews (Smith et al. 2017), focus groups (DOE 2017; NARA 2015) and surveys (Filimonau and Högström 2017; Rains et al. 2017).

Despite their valuable contributions to the field, these studies have tended to overlook the role that stakeholder perceptions potentially or effectively exert on the policy-making process through individual and group narratives (*what* matters, *why* does it and *who* says so), some of which are not always voiced and therefore, acknowledged.

Q-method is suitable for identifying groups of individuals with common attitudes that reflect collective understandings, perspectives and values across "a highly heterogeneous landscape of idiosyncratic knowledge claims and deeply personal worldviews" (Sneegas 2019) apropos the use of AJF. The emerging metanarratives allow to highlight, and potentially negotiate, consensus among individual viewpoints with opposing implications for action (van Eeten 2017), in regard to the contentious and intractable aspects of the alternative fuels debate.

In this study, data collection and analysis for Q-method comprised the following steps:

(1) A concourse consisting of 54 statements (Q-set) was drawn from primary and secondary sources between May and October 2016. Primary sources included personal communications whilst secondary sources included white and grey literature, from which a total of 70 statements were initially extracted. These statements were filtered and categorized into subgroups to represent the variety of viewpoints and latent discourses or

narratives around the environmental, political, technological, social and economic aspects of alternative jet fuels.

(2) A total of 25 participants (P-set) were selected, using Mitchell's et al. (1997) stakeholder classification method (detailed in section 4.2.2), based on each participant's relational attributes toward the ICAO. Participants were approached in person during the Air Transport Action Group's (ATAG) Global Sustainable Aviation conferences (detailed in section 4.2.3), but most data were collected electronically between October 2017 and October 2018.

Seventeen (17) stakeholders agreed to participate in this study, spanning the following sectors: petrochemical and biochemical industries, the media, non-governmental organizations, aircraft manufacturers, fuel suppliers, financial institutions, business associations, consulting services, airports and feedstock producers. Due to the confidential nature of the decision-making processes at the ICAO and to the small universe of stakeholders allowed to participate thereof, respondents were reclassified in broader categories to safekeep their anonymity when reporting the results of this research (i.e. industry B1 and B2 comprise stakeholders with similar commercial activities).

(3) Respondents were asked to rank the 54 statements within the concourse (Q-sorting) using a 7-point Likert scale to express their level of agreement or disagreement with each statement. The ranking used a free or non-standardized type of distribution, followed by a structured interview consisting of three open-ended questions for participants to summarize, clarify or elaborate on any particular statement or aspect within the topic that they felt was relevant to their viewpoint.

(4) The statistical analysis was done using IBM SPSS Statistics to identify groups of individuals with a common attitude structure by correlating participants rather than variables. These groups, called factors, represent common or shared understandings around a particular topic, some of which may have not been anticipated or known a priori (Addams and Proops 2000; Stainton Rogers 1995; Brown 1980; Stephenson 1953). The authors chose the Principal Component Analysis (PCA) to extract factors that were rotated both manually and using Varimax with Kaiser normalization. Statistical significance of factor loading at the 0.01 level was calculated using the following equation (Brown 1980), as well as the Kaiser-Guttman criterion of eigenvalues greater than 1.0 (see Table 4.1):

$$2.58*(1/\sqrt{\text{no. of statements}})$$

(5) The extracted factors were interpreted using the crib sheet system by Watts and Stenner (2012), an approach that methodically organizes each statement within a factor array (view Table A1) to facilitate a more comprehensive and holistic interpretation process. The system consists of identifying the statements ranked the highest and the lowest within each and also relative to other factors, so as to ascertain the aspects that make the most contributions within each factor array (Watts and Stenner 2012). The crib sheet allowed the authors to explore and describe in detail the elements that each metanarrative supports and rejects, in addition to transversally identify the points of consensus and contention amongst them.

4.2.2. Stakeholder identification and salience

R.K. Mitchell's et al. (1997) theory of stakeholder identification and salience was drawn from the management scholarship both as a theoretical framework and as a qualitative tool to add robustness to the overall analysis proposed in this study. The stakeholder classification system served a double purpose: first, as a tool to identify and select the sample of participants for Q-method and, second, to analyze the likelihood of certain metanarratives (*what* matters and *why* does it) to influence future policies and regulations on AJF based on the relational attributes of the stakeholders representing those metanarratives (*who* says so).

Stakeholders were classified according to their possession of power, legitimacy and urgency as dynamic and relational attributes to the ICAO. Mitchell et al. (1997) define: a) power as the coercive, utilitarian or normative capacity of a stakeholder to impose its will over another; b) urgency as the degree to which stakeholder claims call for another's immediate attention, and c) legitimacy as a generalized virtue credited to a stakeholder within a socially constructed system of beliefs, values and norms.

The perceived possession of these attributes (one, two or three of them present) dictates the degree of salience (low, medium, high) that stakeholders have to an individual or an organization (in this case to the ICAO), and thus, the likelihood that stakeholders' claims – reframed through the metanarratives identified with Q-method – will be acknowledged, considered, prioritized and even endorsed by the organization.

4.2.3. Participant observation

As mentioned above, stakeholder interactions are dynamic, multilateral and coalitional rather than static, bilateral and independent; consequently, their relational attributes are variable (they can be gained or lost), they are socially constructed, and stakeholders may not always be aware of their possession nor choose to deliberately make use of them (Mitchell et al. 1997).

This study collected data over the course of four years (see Figure 4.1), where participant observation was used to: (1) gain a better understanding of stakeholder interactions within a particular setting (DeWalt and DeWalt 2002) and (2) to observe changes – if any – to the degree of stakeholder salience over time. Participant observations were conducted during the Air Transport Action Group's (ATAG) Global Sustainable Aviation conferences[8] of 2016 through 2019, totaling four events.

ATAG annual events are well-established within the air transport community and they largely congregate high-profile decision-makers to inform and discuss coordinated approaches to cross-sectoral action on sustainability, climate change and environmental protection. This venue was suitable for selecting a representative sample of stakeholders due to its geopolitical relevance, for conveniently conducting in-person follow-ups with Q-method participants, and to facilitate the interpretation of results through means of repeatedly observing stakeholder interactions (Kawulich 2005; DeWalt and DeWalt 2002).

[8] https://www.atag.org/events.html

4.3. What matters and why does it? Unveiling the metanarratives on alternative jet fuels

Four factors were extracted using Principal Component Analysis (PCA) on IBM SPSS Statistics. The extracted factors (see Table 4.1) accounted for 69% of the study variance with a 0.01 significance (2-tailed) and eigenvalues greater than 1.0. Factors were rotated both manually and using Varimax with Kaiser normalization. The rotation converged in 6 iterations.

Table 4.1. Rotated factor matrix with loadings

Stakeholder	F1	F2	F3	F4
Industry D2	**0.813***	0.404**	0.033	0.073
Industry G	**0.782***	0.028	0.200	-0.138
Industry B2	**0.779***	0.173	0.083	0.006
Industry D1	**0.663***	0.049	0.237	0.026
Industry B1	**0.640***	0.408**	0.297	0.274
Industry C2	**0.535***	0.518**	0.185	-0.055
Int. Organization B	**0.533***	0.456**	0.453**	0.285
Industry A	**0.531***	0.233	0.346	0.519**
Industry E1	0.421**	**0.766***	0.024	0.063
Industry E2	0.183	**0.760***	-0.236	-0.259
Civil Society A	0.273	**0.700***	0.388**	0.259
NGO A	-0.111	**0.675***	0.355**	-0.056
Industry C1	0.381**	**0.563***	0.099	0.483**
Civil Society B	0.122	0.117	**0.799***	-0.188
NGO B	0.257	-0.111	**0.754***	0.261
Int. Organization A	0.223	0.227	**0.677***	0.016
Industry F	0.136	0.114	0.075	**-0.810***
Eigenvalues	7.16	1.84	1.38	1.34
Study variance	42.16	10.86	8.12	7.89
Cumulative variance	**42.16**	**53.02**	**61.14**	**69.03**

*Significance at the 0.01 level (2-tailed).
**Factors with significant loadings at the 0.01 level (2-tailed).

The results presented above show that 8/17 participants were significantly associated to a single factor, while 7/17 and 2/17 participants were so to 2 and 3 factors, respectively (*confounded* Q-sorts). Furthermore, 12 out of the 54 statements in the concourse also showed an abnormal distribution, which typically indicates commonality of viewpoints across the four extracted factors (F1-F4) and, therefore, general consensus among stakeholders over a number of narrative elements on alternative jet fuels.

4.3.1. A common ground: overarching consensus across sectors

The statements showing an abnormal distribution (view Table A2) spanned, in equal proportions, the social, economic, technological, political and environmental dimensions of the alternative jet fuels debate. This suggests a common ground of beliefs and understandings among stakeholders, where the nuances portrayed by each of the four metanarratives representing each of the four extracted factors (F1, F2, F3, F4), can be more amenable to analysis, discussion and, potentially, to negotiation.

Aviation was unanimously recognized as being essential and desirable for the establishment and maintenance of social, political and economic linkages. Participants outstandingly remarked this for the latter, as business relies on face-to-face contact as means to build trust. In the context of the global economy, participants also highlighted the contribution of a robust business travel demand in making the air transport sector resilient to historical price shocks and global crises[9].

Overall, there is general confidence in the dynamism and strong adaptive capacity of the aviation sector to successfully undertake the industry's environmental commitments[10] to address its climate impact. In the view of participants, this entails greater investments in alternative propulsion (e.g. electrical, hybrid, hydrogen fuel cells), aircraft design technologies (e.g. blended wing body, strut-braced wing), alternative jet fuels, infrastructure and operational improvements to meet the mid-century goal of 325 $MtCO_2$ by 2050 (ATAG 2012).

Despite the traction gained by developments on electrical and hybrid propulsion over the past years (Roland Berger 2017), there is general consensus among stakeholders that upscaling these technologies for short-to-medium-haul flights is unlikely before 2040. Furthermore, alternative propulsion technologies are not scalable for long-haul operations in the foreseeable future, thus making aviation reliant on the use of liquid fuels to reduce its net carbon emissions.

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[9] Section 4.5 discusses the impacts on aviation resulting from government restrictions worldwide to contain the spread of COVID-19, as well as the role for AJF in meeting the long-term climate goals set in 2009 by the air transport industry.

[10] Adopted by the International Air Transport Association (IATA) in 2009 and consisting of: (1) an average 1.5% annual improvement in fuel efficiency from 2009 until 2020, (2) achieving carbon-neutral growth from 2020 out to 2050, and (3) halving the sector's net CO_2 emissions by 2050 relative to 2005 levels (ATAG 2012).

Alternative jet fuels are technically viable, and they were widely recognized amongst participants as safe and reliable replacements of petroleum-based aviation fuels. Even so, there is a common preoccupation for AJF to pledge to high sustainability standards through recognized third-party certifiers.

Whereas this concern has stakeholder-specific nuances corresponding to their sectoral interests, needs and constraints (e.g. achieving carbon reduction targets, avoiding competition with food, securing a diversified fuel supply, reducing the risk of environmental penalties, revitalizing local economies, etc.), demonstrated sustainability of AJF is deemed imperative for several reasons. First and foremost, for encouraging governments to adopt policies and regulations conductive to short-term commercial deployment; second, to minimize the sector's reputational risk associated to the extensive effects of land use conversion; third, to standardize fuel purchasing requirements worldwide, and fourth, to stimulate innovation for next-generation AJF conversion pathways.

4.3.2. Understanding the metanarrative nuances

Table 4.2 summarizes the metanarrative nuances and the positioning of stakeholders for each of the four extracted factors (F1, F2, F3, F4), along the social, environmental, economic, technological and political dimensions of the AJF debate. The table is followed by a comprehensive description of each metanarrative to highlight the core elements that they support and reject.

4.3.2.1 Factor 1: An equal level-playing field for everyone

Factor 1 explains 42 percent of the study variance, with 10 participants significantly associated to it. Two out of these participants are also significantly associated to factor 2.

Table 4.2. Narrative nuances and stakeholder positioning

	Factor 1	Factor 2	Factor 3	Factor 4
Environmental	-Weak sustainability approach -AJF hold the greatest climate mitigation potential -CORSIA's net mitigation effects are uncertain, but will shield the aviation sector from externally imposed climate obligations	-Weak sustainability approach -Expected AJF supply is unlikely to be met only with fuels certified as sustainable -CORSIA will promote net reductions through eligible fuels	-Strong sustainability approach -100% fuel replacement with AJF will not suffice to curb future net emissions -Feedstock availability will constraint AJF supply; CAF is unlikely to be fully replaced -AJF sustainability is essentially dependent on feedstock choice -CORSIA should be used as a platform for global uptake of AJF	-Weak sustainability approach -Third-party certifications cannot guarantee a long-term sustainable AJF industry -AJF sustainability is essentially dependent on feedstock choice -CORSIA is crucial for achieving greater CO_2 reductions
Social	-Frequent flying should not be addressed as a climate issue -Social spillovers are attainable through scaling-down AJF production	-Intermodal passenger transport should be encouraged -The air transport sector has a key role in educating users on climate impacts and sustainable choices	-Net CO_2 reductions require reducing air travel demand -Frequent flying should be addressed as a climate issue -Intermodal passenger transport should be pursued	-Intermodal passenger transport will not suffice to curb net emissions from aviation -Transport users have the responsibility to educate themselves about making more sustainable choices
Economic	-Significant market penetration depends on green diesel approval for use in aircraft -More strategic investments are needed to develop and strengthen AJF supply chains	-Airfares should reflect the environmental cost of flying	-Airfares should reflect the environmental cost of flying -Greater investments in electric propulsion are crucial to curb aviation's net emissions	-Intermodal passenger transport ultimately depends on the price competitiveness of alternatives to aviation -Higher airfares will compromise the ability for people to take a flight
Technological	-Technology can decouple the demand for mobility from absolute emissions -Technological progression is preferred over radical change -AJF feedstock-agnostic technologies should be pursued	-Technology can sustainably accommodate future demand for mobility -AJF conversion pathways with high emissions reduction factors should be pursued	-Global supply of AJF is unattainable even if they are technologically viable	-Innovations in aircraft design and propulsion will not suffice to cap net carbon emissions

	Factor 1	Factor 2	Factor 3	Factor 4
Political	-Environmental obligations should be extensive to business, cargo and general aviation -ICAO has a central role in advancing aviation climate efforts -Governments are responsible for creating the conditions pursuant to short-term commercial deployment of AJF -Climate obligations should equally apply to all countries -Greater involvement of developing countries in ICAO's technical work is needed	-Climate obligations should equally apply to all countries -ICAO's climate action strategy requires more ambition -ICAO should make Action Plans mandatory and auditable to foster compliance on environmental commitments by Member States.	-Environmental obligations should be extensive to business, cargo and general aviation -The aviation community has downplayed its environmental impact -CORSIA is a deterrent to net sectoral emissions reductions -Governments have the responsibility to lead and enforce climate action -Climate obligations should uphold the principle of common but differentiated responsibilities (CBDR)	-Climate obligations should equally apply to all countries -Governments have the responsibility to lead and enforce climate action -The aviation community has actively pursued reducing its environmental impact -The Chicago Convention may not be suitable anymore to address the challenges of sustainable development

The metanarrative represented by factor 1 supports a weak sustainability approach[11] to international aviation's growth. Stakeholders' interests and priorities attend to greater investments and financial support for supply chain development (e.g. capital grants, debt guarantees), diversification of AJF conversion pathways by means of assistance programs, and ensuring an equal level-playing field with road transport through sector-tailored policy and regulations. This metanarrative also emphasizes the responsibilities of national governments to create the conditions for attaining near-term deployment of AJF, and of the ICAO to pursue greater climate ambition with equal obligations for its member states.

Notwithstanding the general uncertainty about the effectiveness of the ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)[12] for achieving carbon-neutral

[11] The concept of weak sustainability refers to the replacement of natural capital by human capital (social and manufactured) for the preservation of economic growth. Conversely, a strong sustainability approach advocates for an economic development where natural capital and human capital are irreplaceable (Ayres et al. 2001; Gowdy 2000; Goodland 1995). For an in-depth discussion of the social, economic and environmental implications of a weak sustainability approach within the air transport sector, see Soria Baledón and Kosoy (2018).

[12] CORSIA is a global offsetting scheme adopted in 2016, to compensate for the short-to-mid-term CO_2 emissions from international aviation's growth that exceed the 2019 baseline (originally 2019/2020) for carbon-neutral growth

growth between 2021 and 2035, the scheme is deemed relevant for coordinating environmental efforts among member states and to shelter the industry from out-of-sector climate financing measures (e.g. carbon tax, passenger duties).

The discursive elements of this metanarrative place great confidence that the use of alternative jet fuels will allow for significant CO_2 and non-CO_2 emissions reductions once the market reaches the 2% tipping point. This scenario is more likely to happen if: first, research and development prioritize fuel conversion technologies that are feedstock-agnostic and, second, green diesel is granted ASTM D7566 approval for use in civil and military aircraft.

4.3.2.2 Factor 2: Environmental sustainability comes first

Factor 2 explains 10 percent of the study variance. Nine participants are significantly associated with this factor, where four of them are also significantly associated to factor 1.

Although stakeholders concede priority to the environment over other geopolitical concerns, this metanarrative also has a weak sustainability approach to international aviation's growth, where there is optimism that cross-sectoral collaboration will make it possible to accommodate future demand for mobility, while keeping absolute CO_2 emissions below the carbon-neutral growth baseline.

The claims represented by factor 2 are predominantly technical and they focus on the existing knowledge, data and methodological gaps of third-party sustainability certifications for AJF. Stakeholders advocate for comprehensive and robust certification schemes for AJF capable of ≥80% lifecycle CO_2 reductions while avoiding mid-to-long term risks from land use conversion, biological invasion, biodiversity loss, etcetera. Ideally, CORSIA's sustainability criteria for CORSIA eligible fuels shall pursue equal ambition if the scheme is to favor net carbon reductions over offsetting emissions.

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after improvements in technology and operations (A40-19; A39-3). Environmental obligations under this market-based scheme can be met through the use of alternative jet fuels that comply with the ICAO's sustainability criteria for CORSIA eligible fuels (ICAO 2019b).

This metanarrative pursues greater environmental commitment from the ICAO and its member states, who have the agency for introducing and enforcing economy-wide regulations that procure a compromise between growth and sustainability. Factor 2 equally recognises the role of the aviation industry in raising awareness about the impacts of flying, but also in empowering users to make more sustainable choices (e.g. offsetting their flights' emissions, flying with airlines that use alternative fuels, reducing their cabin waste).

4.3.2.3 Factor 3: Addressing emissions demands a strong sustainability approach

This factor explains 8 percent of the study variance. Six participants are significantly associated with this factor; one participant is also significantly associated to factor 1 and two others are significantly associated with factor 2.

The metanarrative for factor 3 is representative of a strong sustainability approach, where stakeholders advocate for measures to decelerate sectoral growth in order to prevent absolute CO_2 emissions to exceed the potential reductions from technology improvements, operational efficiencies and from the use of alternative jet fuels.

AJF are considered improbable to entirely replace petroleum-based fuels for as long as they require blending with conventional Jet A/A-1 to ensure full compatibility with the existing fuels systems. This concern also recognizes limitations in feedstock quality, availability and sustainability to meet the global demand of ~570 billion litres over the next decades (ATAG 2020a). Thereupon, this metanarrative strongly supports transitioning to aircraft propulsion systems that are less reliant on liquid fuels (e.g. electrical and hybrid-electric architectures) for effectively addressing long-term CO_2 and non-CO_2 emissions.

In a shorter time horizon, some of the proposed measures consist of: 1) airfares that incorporate environmental externalities in their price breakdown, 2) restrictions on frequent flying programs to disincentivize non-essential travel, 3) high stringency and robustness in CORSIA's sustainability criteria for CORSIA eligible fuels to encourage direct emissions abatement over offsetting, 4) incentives to promote intermodal passenger transport, and 5) extending climate obligations to other types of aviation except for medical and humanitarian aid.

4.3.2.4 Factor 4: Improving the business as usual

This factor explains 7 percent of the study variance. Although 3 participants are significantly associated to this factor, only one of them is primarily associated to it, while the other two participants have higher loadings on factors 1 and 2 respectively. The positive and negative loadings (bipolarity) on factor 4 were accounted for during the interpretation process using the crib sheet system by Watts and Stenner (2012).

This metanarrative has a weak sustainability approach to international aviation's growth, and it is predominantly conservative and risk averse to environmental policies, regulations and measures that could impose financial burdens on the sector or negatively impact air traffic demand.

Stakeholders associated to this factor acknowledge the likelihood of net aviation emissions to unavoidably outpace the reductions achieved through technological efficiencies, operational measures and the use AJF, thus heavily relying on carbon offsetting to attain the industry's climate aspirational goals. Hence, AJF are not anticipated to make a substantial contribution to abate aviation emissions beyond their use as CORSIA eligible fuels.

4.4. Who says so? Stakeholder positioning and the art of crafting coalitions

To explore the likelihood of the four metanarratives analyzed thus far or some elements thereof (*what* matters and *why* does it) to influence future policies and regulations on AJF for international aviation, stakeholders were classified according to their possession of power, legitimacy and urgency (Mitchell et al. 1997) as dynamic and relational attributes to the ICAO.

The perceived possession of these attributes (one, two or three of them present) dictates the degree of salience (low, medium, high) that stakeholders have to the ICAO, and thus, the prospect of stakeholders' claims (*who* says so) to be acknowledged, considered, prioritized and even endorsed by the organization. Figure 4.2 depicts the positioning of stakeholders based on the metanarratives they represent and their degree of salience in relation to the ICAO.

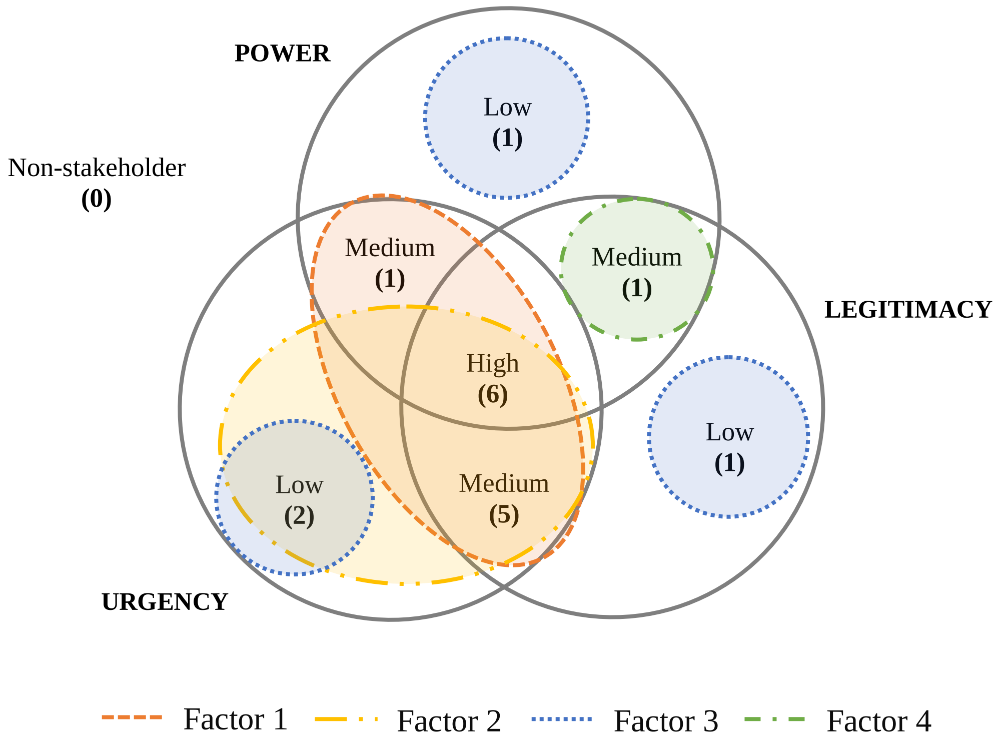

Figure 4.2. Salience and positioning of stakeholders

The metanarratives associated to factors 1 and 2 are primarily comprised by medium to highly salient stakeholders with an industry background, whose possession of power, legitimacy and urgency has remained stable over the past four years of data collection for this study. Most of these stakeholders have a longstanding relationship to the ICAO and have actively participated in the organization's climate deliberations and formulation of environmental policy, whether as observers and/or technical experts within advisory groups to its Council. In contrast, less salient stakeholders have often been excluded from participation (Farand 2019; Piera 2015; Lyle 2014; A39-WP/208).

The intensified pressure and public scrutiny on the aviation sector effected by climate geopolitics, particularly since the ratification of the Paris Agreement and the publication of the special report on the impacts of global warming by the Intergovernmental Panel on Climate Change (IPPC), did not seem to affect the degree of salience of stakeholders associated to factors 3 (low) and 4 (medium). Even so, the positioning of low-salient stakeholders in relation to factors 1 and 2 (as depicted in Figure 4.2) denotes the possibility for the ICAO to acknowledge some of their claims by means of collaborative arrangements with medium and highly salient stakeholders.

The institutional setting and governing structure of the ICAO restricts direct participation in internal deliberations and policy-making to its constituency. Therefore, stakeholder collaboration could entail the nomination of technical experts to the ICAO Council's Advisory Group on CORSIA (AGC)[13], its Technical Advisory Body (TAB) and to the Committee on Aviation Environmental Protection (CAEP) and its technical subgroups (e.g. fuels task group, long-term aspirational goal task group and others). This could be done through a system of quotas for improving the balance of geographical representation within the organization, and for encouraging stakeholder participation from outside the air transport industry (e.g. NGOs and CSOs).

Although this type of collaborative approach may not address the wider and enduring concerns about the lack of transparency, inclusion and accountability in the negotiations and decision-making processes at the ICAO (Farand 2019; Piera 2015; Lyle 2014; A39-WP/208), it has the potential to bring valuable expertise from low-salient and non-stakeholders into the formulation of environmental policy.

4.4.1. Climate geopolitics and non-stakeholders: transcending Mitchell's method

Mitchell et al. (1997) define non-stakeholders as individuals, groups or organizations that lack power, legitimacy or urgency as relational attributes to an organization and, consequently, are perceived as having no salience thereof. The International Coalition for Sustainable Aviation (ICSA) has been hitherto the sole accredited stakeholder by the ICAO, on a limited basis, to represent global civil society in technical discussions on environmental issues. The restrictions this has thus placed upon citizen representation and participation at the ICAO to address international aviation's climate impact, have engendered an increased activism by non-stakeholders (i.e. individuals and organizations) with effecting geopolitical ramifications.

[13] Formerly the Environmental Advisory Group (EAG).

For example, the *flygskam* or fly shame movement that emerged in Sweden in 2018, aimed at discouraging people from flying by reframing non-essential travel as a reprehensible act within the context of the global climate crisis (Mkono 2020; Söderberg and Wormbs 2019). The movement – which cannot be classified using Mitchell's et al. method – rapidly gained international attention on social media platforms and accrued a strong support across Europe, where the term has been adapted to fit the climate action narratives of countries such as Finland (*lentohapea*), the Netherlands (*vliegschaamte*) and Germany (*Flugscham*).

In 2019, passenger numbers for domestic and short-haul routes in Europe showed a steady decline (~5 to 10 percent), along with a corresponding surge in rail travel (Reynolds 2020). Even when the COVID-19 pandemic makes difficult to assess the potential long-term effects of the *flygskam* movement on global demand, the growing anti-aviation sentiment has prompted a variety of responses from the industry and governments alike.

On the industry side, a rising number of air carriers have turned to carbon offsetting programs, fleet renewals, and to global outreach campaigns (e.g. IATA's Fly Aware) to inform the public about the industry's progress on attaining its climate commitments, and to provide air transport users with options to reduce the environmental footprint of their travels. To a smaller extent, airlines have set mid and long-term voluntary carbon-neutrality goals, and some have also partnered with fuel producers to forward-purchase alternative jet fuels through off-take agreements (Martín 2020; Reynolds 2020).

Largely in European countries[14], the *flygskam* movement accelerated the development and the adoption of environmental policies and regulations in the form of carbon pricing (e.g. eco-taxes), intermodal passenger transport guidelines, passenger fees and proposals to mandate volumetric targets for alternative jet fuels. Particularly in the European Union, these measures are framed within the ReFuelEU Aviation initiative, conductive to support and advance the mid-century decarbonization goals of the European Green Deal (EC 2019) through the use of AJF.

[14] Including Norway, Sweden, the UK, Switzerland, the Netherlands, Germany, France and Spain.

Additional policy and regulatory options include revisions to: 1) the EU Emissions Trading System Directive (EU ETS) to reduce the allowances allocated for free to aircraft operators[15]; 2) the recast Renewable Energy Directive (REDII) to increase the multiplier of 1.2x currently applicable to AJF, and 3) the Energy Taxation Directive (ETD) to end the exemption for petroleum-based aviation fuel taxation and Value Added Tax (VAT).

4.5. Bridging the metanarratives: what role for AJF in post-pandemic times?

By April 2020, the global outbreak of COVID-19 had grounded over 80% of the airlines' fleet (Pearce 2020), leading to multibillion dollar bailouts to rescue aircraft operators from near-shutdown[16] (Jasper et al. 2020; Xu 2020). In response, the ICAO Council approved later in June to only use 2019 emissions (~580 $MtCO_2$) during the pilot phase (2021-2023) for the determination of CORSIA's baseline[17].

As the net financial loss of the aviation industry was expected to reach USD 118.5 billon by the end of 2020 (IATA 2020c), the restoration of air travel services became a global priority, particularly in countries heavily reliant on trade and tourism. The redirected focus on the economic recovery of aviation has abridged the chances for strong sustainability metanarratives (e.g. factor 3 and grassroot movements such as the European *flygskam*), to accrue highly salient stakeholders capable of advancing an agenda based on structural changes at the ICAO.

At the same time, all four metanarratives identified in this study share a common ground of beliefs and understandings (section 4.3.1) that could facilitate the discussion, negotiation and consensus of seemingly intractable aspects about the role for AJF in rebuilding the sector and for advancing the industry's long-term climate goals. The significant loading of participants onto more than one factor (see Table 4.1) also indicates convergence of viewpoints across factors beyond those listed

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[15] At present, 82% of the allowances for aviation are granted for free (~30.5 million), 15% are auctioned (~5 million) and 3% are reserved for distribution to new market entrants and fast-growing aircraft operators (~1 million) (IIA-Ares(2020)3515933).

[16] https://www.transportenvironment.org/what-we-do/flying-and-climate-change/bailout-tracker on July 16, 2020.

[17] In 2022, the Council will present at the 41st session of the Assembly a proposal to amend Resolution A40-19 to also use only 2019 carbon emissions beyond CORSIA's pilot phase (2024-2035).

in Table A2 and thus, additional opportunities for collaboration among stakeholders associated to different metanarratives.

As climate action is likely to remain highly visible on the global agenda over years to come, the attainment of the aviation sector's commitments is contingent on countries' immediate responses to the pandemic. This is to the point insofar capital raised through government bailouts, the repayment of liabilities, equity financing and bank loans could compromise the industry's capacity to adhere to existing and future environmental commitments, as airline debts might have exceeded USD 500 billion in 2020 (Jasper et al. 2020).

Last year, the low price for petroleum-based jet fuel[18] gave airlines a respite to their operating costs but it also provided little incentive to use AJF, whose production costs stayed constant throughout the year. Furthermore, commercial deployment of alternative jet fuels will still require investments for approximately USD 1.4 billion per annum[19] for attaining 2% of market penetration by 2025 (IATA 2020b; Staples et al. 2018). Without incentives, the European Commission forecasts AJF to reach only 2.8% of the total CAF supply in Europe by 2050, with similar projections made by the International Air Transport Association (IATA) for the rest of the world (IIA-Ares(2020)1725215).

Assuming that the structural drivers for growth remain largely unaffected by the pandemic, this figure is relevant since the air traffic demand is expected to recover to pre-crisis levels (~4.1% annual sectoral growth with an associated ~2.9% annual increase in emissions) within the next half-decade (WBG 2020; Pearce 2020; A40-WP/54). If so, emissions from international and domestic aviation are forecast to reach 1,820 $MtCO_2$ by 2050[20]; closely double of those from all commercial operations in 2018 (ICAO 2019a). In this scenario, maintaining carbon neutral growth out to 2050 will require almost full replacement of petroleum-based jet fuels with AJF capable of lifecycle CO_2 reductions between 80% to 100% (ATAG 2020a; ICAO 2019a).

[18] https://www.iata.org/en/publications/economics/fuel-monitor/ on July 15, 2020.
[19] For reference, in 2018 the US government allocated USD 4 billion to renewable diesel under the Renewable Fuel Standard (RFS2) (IATA 2020b).
[20] This estimate does not consider the net radiative forcing effect of CO_2 and non-CO_2 emissions at cruise altitude (Moore et al. 2017; Penner et al. 1999).

4.5.1. International climate geopolitics past the triennial assembly

In its 40th session, the ICAO Assembly reaffirmed its climate commitments and since, its Council has formally[21] undertaken the assessment of a long-term aspirational goal and a roadmap for implementation to be agreed upon at the 41st Assembly session in 2022 (A40-18). The results of the technical work conducted by CAEP at that point, plus those collected through the annual AJF stocktaking assessments, should inform no later than 2025 the *2050 ICAO Vision on Sustainable Aviation Fuels* for the purpose of setting quantifiable targets for AJF as well as for CO_2 reductions.

As observed in section 4.4, the nomination of technical experts to the ICAO Council's advisory groups and committees is a form of stakeholder collaboration that has the potential to bring valuable expertise from low-salient and non-stakeholders into the formulation of environmental policy (see Figure 4.2). Even so, there are a limited number of seats and the nomination process could take several days up to a few months depending on the type of expert nomination sought (e.g. members, observers, co-rapporteurs, etc.).

In recognition to the limitations for ensuring a balanced representation of stakeholders in decision-making processes at the ICAO, the past decade has seen growing outreach and collaboration on AJF among stakeholders worldwide from within and outside the air transport sector. Spanning from fuel producers to agricultural associations, academia, capital markets and others, stakeholder collaboration has taken place through conferences, workshops, public-private partnerships, innovation programs, commercial initiatives, etcetera.

Whereas these collaborative arrangements do not address the structural barriers to direct participation of low-salience and non-stakeholders in the ICAO's technical discussions on AJF, they have created an expansive community of interest for advancing a post-pandemic recovery agenda more consistent with the ambitions of the Paris Agreement. To illustrate this point, several multi-stakeholder partnerships were announced throughout 2020 to advance research and development of fuel conversion technologies and for upscaling global AJF production.

[21] The ICAO Council has had the mandate to explore the feasibility of a long-term climate goal for international aviation since the 37th Assembly session in 2010 (A37-19).

Most notably in Europe, these partnerships have developed amidst an increasing number of national governments pledging to fully decarbonize their economies between 2030 and 2050[22]. The establishment of regulatory frameworks and mechanisms to finance the European energy transition, has encouraged a comparable number of individual airlines, airline consortia, air transport industry coalitions and global multi-stakeholder alliances, to also set carbon-neutrality targets by mid-century (Costa Figueira 2020; EU Aviation Round Table 2020; Martín 2020; Reynolds 2020; WEF 2020).

The World Economic Forum's Clean Skies for Tomorrow (CST) appropriately exemplifies a strategic way to engage stakeholders from diverse backgrounds and with different degrees of salience, into initiatives with high impact and international visibility. Presently, the ICAO participates as advisory partner to the CST and since 2017, it has also organized public workshops and stocktaking seminars[23] to include stakeholders in the process of defining quantifiable targets for the 2050 *ICAO Vision on Sustainable Aviation Fuels*, as convened at the Second Conference on Aviation and Alternative Fuels (CAAF/2-SD3).

In regard to the potential role for AJF within the ICAO's broader environmental protection strategy, as of July 2020, 88 countries representing 76.82% of international air traffic intend to voluntarily participate in CORSIA from its outset[24]. Even so, it is unlikely that a noteworthy proportion of the scheme's obligations will be met utilizing AJF during the pilot (2021-2023) and the first phases (2024-2026) in the absence of comprehensive and supportive policies and regulations.

4.6. Concluding remarks: tools for improving environmental governance

This was the first study on alternative jet fuels to investigate stakeholder perceptions using a combination of qualitative and mixed methods for analyzing subjectivity. Stakeholder viewpoints have been progressively acknowledged in socio-environmental research as the base for

[22] Norway has pledged to decarbonize its economy by 2030, Finland by 2035, Iceland by 2040, Sweden by 2045 and the rest of the European Union plus the United Kingdom have committed to reach climate neutrality by 2050.
[23] https://www.icao.int/environmental-protection/Pages/SAF_Stocktaking.aspx on December 14, 2020.
[24] https://www.icao.int/environmental-protection/CORSIA/Pages/state-pairs.aspx on July 5, 2020.

understanding *what* matters, *why* does it and *who* says so in the policy process, and as paramount to inform and improve decision-making and environmental governance.

The methodological approach and the analysis presented here, aimed at exploring and gaining a better understanding of the metanarratives influencing the adoption of policies and regulations by the ICAO concerning the use AJF to reduce carbon emissions from international aviation.

This study showed that three out of the four metanarratives derived from the application of Q-method have a weak sustainability approach to international aviation's growth (F1, F2, F4). Yet, they all encompass a number of discursive elements (i.e. political, economic, technological, social and environmental) where an overarching consensus along with element-specific consensus among stakeholders were observed.

In the context of advancing a sectoral recovery agenda cemented on a strong sustainability approach (F3), the revealed consensus entails opportunities for low-salience stakeholders to have their claims on AJF acknowledged and considered by the ICAO as inputs for policy-making. As exemplified throughout section 4.5, this will depend on the type of coalitions and/or collaborations forged between low and more salient stakeholders, and by the way their individual claims are reframed and articulated in metanarratives.

By means of classifying stakeholders based on their relational attributes to the ICAO, this study also revealed the limitations of Mitchell's et al. (1997) method to explain the destabilizing and residual effects that social movements – and not stakeholders – such as the European *flygskam* can inflict on the aviation sector[25].

Despite the valuable contributions of previous studies on stakeholder perceptions that were conducted using well-established qualitative methods (e.g. focus groups, interviews, surveys), the application of Q-method was comparatively advantageous for unveiling collective narratives on AJF previously unknown to the authors and ofttimes to the study participants themselves.

[25] With reference to the public sentiment on aviation as the vector for the COVID-19 pandemic, this observation equally applies.

Nonetheless, there are a number of caveats to this study resulting from limitations inherent to the application of Q-method. Firstly, metanarratives emerging from Q-method may not comprehend all possible perspectives on the domain of research. Secondly, the existing body of socio-environmental research involving Q-method is highly heterogeneous in terms of methodological practice (Sneegas et al. 2021). Sneegas et al. (2021) suggest that withal the prolific growth of Q-method research over the past 20 years, the scant exchange of trends, best practices, analytical tools, common gaps and innovative solutions among research groups globally is abiding.

To exemplify this issue, none of the freeware and proprietary software available in 2016 for creating and administering Q-sorts online were deemed to offer a user-friendly interface for the authors nor the participants of this study, resulting in days of laborious manual data entries and processing. However, the mandated lockdowns and social gathering restrictions worldwide to contain the pandemic throughout 2020, prompted the rapid development of online tools (e.g. Easy HtmIQ, Ken-Q/KADE) that promise a more standardized and efficient application of Q-method for collecting and processing data.

Whilst a large number of participants (P-set) does not amount to a robust analysis in Q-method because participants act as variables rather than items (Watts and Stenner 2012; Brown 1980; Stephenson 1953), access to information and to stakeholders was ofttimes challenging. This was particularly true for data protected by non-disclosure agreements (NDAs) as standard practice (Farand 2019; Piera 2015; Lyle 2014; A39-WP/208). Instances of confidentiality encompass ongoing discussions at the ICAO as well as white and grey literature, whether or not they contain politically sensitive and/or proprietary data.

In consideration to the obligations contracted by signatories of these NDAs over and above their perceived risk of bearing *unlimited* legal liability upon infringement thereof (Farand 2019), the authors rigorously followed the best academic practices (detailed in section 4.2.1) to safekeep the anonymity of the stakeholders who agreed to participate in this study[26].

[26] Each participant signed an informed consent form approved by the Research Ethics Board Office of McGill University (REB File no.175-0917) detailing the purpose of the study together with the handling of their personal information and of the data collected by the authors.

Beyond the work of the ICAO, there is a significant challenge – but also opportunity to replicate studies like this one – in addressing CO_2 emissions from domestic aviation of large emitters including the US, China, India and Brazil[27]. This, considering that most climate plans submitted under the Paris Agreement, known as Nationally Determined Contributions or NDCs, do not appropriately account for the required economy-wide carbon reductions to limit global warming to 1.5°C above pre-industrial levels (Masson-Delmotte et al. 2018).

Understanding the development of AJF as a source of energy of mounting geopolitical and economic relevance demands the acknowledgement of stakeholders' role in the policy process, as they can bring valuable expertise into the formulation of more transparent, balanced, fair and inclusive mechanisms for environmental governance.

Fertile areas for collaboration include: a) research and testing pursuant to eliminate the blending limits for AJF certified under ASTM D7566, b) development of conversion pathways with high sustainability profiles, c) public and private partnerships (PPPs) for de-risking investments in AJF, d) harmonization of technical and sustainability certification schemes, e) engagement of air transport users in AJF financing through individual climate action, etcetera.

Yet, at its most basic level, a better appreciation of *what* matters, *why* does it and *who* says so will be highly advantageous for researchers and policy-makers alike, to navigate the complexity and dynamism of the air transport's climate geopolitics in times of a new global reality.

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[27] Excluding the US, these and other large aviation emitters are expected to join CORSIA for its second phase (2027-2035).

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Declaration of interest

The authors have no conflicts of interest to disclose.

Literature cited

1. ACRP (2018), State of the industry report on air quality emissions from sustainable alternative jet fuels, National Academy of Sciences. Retrieved from: http://nap.edu/25095

2. Addams H. and J. Proops (eds.) (2000), *Social discourse and environmental policy: an application of Q methodology*, Massachusetts: Edward Elgar Publishing Inc.

3. Atsonios K., Kougioumtzis M.A., Panopoulos K.D. and E. Kakaras (2015), Alternative thermochemical routes for aviation biofuels via alcohols synthesis: Process modeling, techno-economic assessment and comparison, *Applied Energy*, 138:346-366.

4. ATAG (2020a), Waypoint 2050 (1st edition). Retrieved from: https://aviationbenefits.org/media/167187/w2050_full.pdf

5. ATAG (2020b), Aviation: Benefits beyond borders. Retrieved from: https://aviationbenefits.org/media/167186/abbb2020_full.pdf

6. ATAG (2020c), Aviation's energy transition. Retrieved from: https://aviationbenefits.org/downloads/fact-sheet-5-aviations-energy-transition/

7. ATAG (2020, December 6), Sustainable aviation fuel. Retrieved from: https://aviationbenefits.org/environmental-efficiency/climate-action/sustainable-aviation-fuel

8. ATAG (2020, April 13), The leading edge. Retrieved from: https://aviationbenefits.org/environmental-efficiency/climate-action/sustainable-aviation-fuel/the-leading-edge/

9. ATAG (2018), Aviation: Benefits beyond borders. Retrieved from: https://aviationbenefits.org/media/166344/abbb18_full-report_web.pdf

10. ATAG (2017), Beginner's guide to sustainable aviation fuel (3rd edition). Retrieved from: https://www.atag.org/component/attachments/attachments.html?id=604

11. ATAG (2012), Powering the future of flight: The six easy steps to growing a viable aviation biofuels industry. Retrieved from: http://www.atag.org/component/downloads/downloads/152.html

12. Ayres R.U., van den Bergh J.C.J.M. and J. M. Gowdy (2001), Strong versus weak sustainability: economics, natural sciences and "consilience", *Environmental Ethics*, 23(2):155-168.

13. Bann S.J., Malina R., Staples M.D., Suresh P., Pearlson M., Tyner W.E., Hileman J.I. and S.R.H. Barret (2017), The costs of production of alternative jet fuel : A harmonized stochastic assessment, *Bioresource Technology*, 227:179-187.

14. Barry J. and J. Proops (1999), Seeking sustainability discourses with Q methodology, *Ecological Economics*, 28(3):337-345.

15. Bosch J., de Jong S.A., Hoefnagels R. and R. Slade (2017), Aviation biofuels : strategically important, technically achievable, tough to deliver, Grantham Institute, Imperial College London. Retrieved from : https://www.imperial.ac.uk/media/imperial-college/grantham-institute/public/publications/briefing-papers/BP-23-Aviation-Biofuels.pdf

16. Boyd, R. (2019), Climate change mitigation, in ICAO (2019), Destination green: the next chapter, pp.174-176. Retrieved from: https://www.icao.int/environmental-protection/Documents/ICAO-ENV-Report2019-F1-WEB%20%281%29.pdf

17. Brown, S.R. (1980), *Political subjectivity: applications of Q Methodology in political science*, New Haven: Yale University Press.

18. Costa Figueira, J. (2020, September 18), Oneworld member airlines commit to net-zero carbon emissions by 2050, Climate Action. Retrieved from: https://www.climateaction.org/news/oneworld-member-airlines-commit-to-net-zero-carbon-emissions-by-2050

19. de Jong, S.A. (2018), *Green horizons : On the production costs, climate impact and future supply of renewable jet fuels*, Utrecht : Copernicus Institute of Sustainable Development.

20. de Jong S.A., van Stralen J., Londo M., Hoefnagels R., Faaij A. and M. Junginger (2018), Renewable jet fuel supply scenarios in the European Union in 2021-2030 in the context of proposed biofuel policy and competing biomass demand, *GCB Bioenergy*, 10:661-682.

21. Deane J.P. and S. Pye (2018), Europe’s ambition for biofuels in aviation. A strategic review of challenges and opportunities, *Energy Strategy Reviews*, 20:1-5.

22. DeWalt K.M and B.R. DeWalt (2002), *Participant observation : a guide for fieldworkers*, Walnut Creek, CA: AltaMira Press.

23. DOE (2017), Alternative aviation fuels : overview of challenges, opportunities and next steps. Retrieved from: https://www.energy.gov/sites/prod/files/2017/03/f34/alternative_aviation_fuels_report.pdf

24. Durning, D. (2006), Using Q-methodology to resolve conflicts and find solutions to contentious policy issues, in R. Ahmad (ed.), *The role of public administration in building a harmonious society*, Mandaluyong : Asian Development Bank, pp.601-620.

25. Durning, D. (1999), The transition from traditional to postpostitivist policy analysis : A role for Q-methodology, *Journal of Policy Analysis and Management*, 18(3) :389-410.

26. European Commission (2019, December 11), The European Green Deal. Retrieved from: https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf

27. EU Aviation Round Table (2020), Aviation Round Table Report on the recovery of European Aviation. Retrieved from: https://euagenda.eu/upload/publications/aviation_round_table_declaration_final_16.11.2020_v2.pdf.pdf

28. Farand, C. (2019, September 12), Aviation's black box: non-disclosure agreements, closed doors and rising CO_2, Climate Home News. Retrieved from: https://www.climatechangenews.com/2019/09/12/non-disclosure-agreements-closed-doors-rising-co2-uns-aviation-body/

29. Filimonau V. and M. Högström (2017), The attitudes of UK tourists to the use of biofuels in civil aviation: an exploratory study, *Journal of Air Transport Management,* 63:84-94.

30. Fortier M.O.P., Roberts G.W., Stagg-Williams S.M. and B.S.M. Sturm (2014), Life cycle assessment of bio-jet fuel from hydrothermal liquefaction of microalgae, *Applied Energy*, 122:73-82.

31. Gazis E., Mawhood B., Slade R., de Jong S.A. and R. Hoefnagels (2016), Stakeholder analysis of the renewable jet fuels innovation system, Climate-KIC RENJET Future Renewable Jet Fuel Supply Chains Project.

32. Gegg, P., Budd L. and S. Ison (2015), Stakeholder views of the factors affecting the commercialization of aviation biofuels in Europe, *International Journal of Sustainable Transportation*, 9(8) :542-550.

33. Gegg P., Budd L. and S. Ison (2014), The market development of aviation biofuel: drivers and constraints, *Journal of Air Transport Management*, 39:34-40.

34. Goodland, R. (1995), The concept of environmental sustainability, *Annual Review of Ecology and Systematics*, 26:1-24.

35. Gowdy, J.M. (2000), Terms and concepts in ecological economics, *Wildlife Society Bulletin*, 28(1):26-33.

36. Hajer, M.A. (1997), *The politics of environmental discourse: ecological modernization and the policy process*, Oxford: Clarendon.

37. Han J., Elgowainy A., Cai H. and M.Q. Wang (2013), Life-cycle analysis of bio-based aviation fuels, *Bioresource Technology*, 150:447-456.

38. IATA (2020a), Sustainable aviation fuel (SAF) fact sheet. Retrieved from: https://www.iata.org/contentassets/8dc7f9f4c38247ae8f007998295a37d5/saf_general-fact-sheet_advocacy_june2020.pdf

39. IATA (2020b), Proceedings from the Sustainability and Environment Advisory Council meeting [SEAC/2], March 24-25.

40. IATA (2020c, November 24), "Deep losses continue into 2021", Press release no.95. Retrieved from: https://www.iata.org/en/pressroom/pr/2020-11-24-01/

41. IATA (2020, July 15), Jet fuel price monitor. Retrieved from: https://www.iata.org/en/publications/economics/fuel-monitor/

42. ICAO (2020, December 14), SAF Stocktaking – what is it about? Retrieved from: https://www.icao.int/environmental-protection/Pages/SAF_Stocktaking.aspx

43. ICAO (2020, July 5), CORSIA States for Chapter 3 State Pairs. Retrieved from: https://www.icao.int/environmental-protection/CORSIA/Pages/state-pairs.aspx

44. ICAO (2019a), Destination green: the next chapter. Retrieved from: https://www.icao.int/environmental-protection/Documents/ICAO-ENV-Report2019-F1-WEB%20%281%29.pdf

45. ICAO (2019b), CORSIA Sustainability criteria for CORSIA eligible fuels. Retrieved from: https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2005%20-%20Sustainability%20Criteria.pdf

46. Jasper C., Ryan C. and A. Kotoky (2020, May 2), An $85 billion rescue may only prolong the pain, Bloomberg. Retrieved from: https://www.bloomberg.com/news/articles/2020-05-02/coronavirus-airline-bailouts-a-guide-to-85-billion-in-state-aid

47. Kawulich, B.B. (2005), Participant observation as a data collection method, *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research, 6*(2).

48. Kivits R. and M.B. Charles (2015), Aviation planning policy in Australia: identifying frames of reference to support public decision making, *Journal of Air Transport Management*, 47:102-111.

49. Kroesen M. and C. Bröer (2009), Policy discourse, people's internal frames and declared aircraft noise annoyance: an application of Q-methodology, *The Journal of the Acoustical Society of America*, 126(1) :195-207.

50. Lim, C. (2015), Analysis of stakeholder perspectives for biofuel policy using Q-methodology in Korea, *New & Renewable Energy*, 11(1) :36-48.

51. Lyle, C. (2019, May 3), The pressing need for a strategy to ramp up ambition on mitigation emissions from aviation, GreenAir Online. Retrieved from: https://www.greenaironline.com/news.php?viewStory=2587

52. Lyle, C. (2014, February 6), Mitigating international air transport emissions through a global measure: time for some lateral thinking, GreenAir Online. Retrieved from: http://www.greenaironline.com/news.php?viewStory=1820

53. Martín, H. (2020, February 7), Travel by plane and you might get "flight shamed". This worries airlines, Los Angeles Times. Retrieved from: https://www.latimes.com/business/story/2020-02-07/flight-shaming-airlines-climate-change-greta-thunberg

54. Masson-Delmotte V., Zhai P., Pörtner H.-O., Roberts D., Skea J., Shukla P.R., Pirani A., Moufouma-Okia W., Péan C., Pidcock R., Connors S., Matthews J.B.R., Chen Y., Zhou X.,

Gomis M.I., Lonnoy E., Maycock T., Tignor M. and T. Waterfield (eds.) (2018), Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development and efforts to eradicate poverty. Retrieved from: https://www.ipcc.ch/sr15/download/

55. Mitchell R.K., Agle B.R. and D.J. Wood (1997), Toward a theory of stakeholder identification and salience: defining the principle of who and what really counts, *The Academy of Management Review*, 22(4) :853-886.

56. Mkono, M. (2020), Eco-anxiety and the flight shaming movement: implications for tourism, *Journal of Tourism Futures*, 6(3):223-226.

57. Moore R.H., Thornhill K.L., Weinzierl B., Sauer D., D'Ascoli E., Kim J., Lichtenstern M., Scheibe M., Beaton B., Beyersdorf A.J., Barrick J., Bulzan D., Corr C.A., Crosbie E., Jurkat T., Martin R., Riddick D., Shook M., Slover G., Voigt C., White R., Winstead E., Yasky R., Ziemba L.D., Brown A., Schlager H. and B.E. Anderson (2017), Biofuel blending reduces particle emissions from aircraft engines at cruise conditions, *Nature*, 543:411-415.

58. Nair S. and H. Paulose (2014), Emergence of green business models: the case of algae biofuel for aviation, *Energy Policy*, 65:175-184.

59. NARA (2015), Aviation fuel supply chain stakeholder perceptions of sustainable alternative jet fuel, presented at the Northwest Advanced Renewables Alliance's Annual Meeting, Spokane, WA. [PowerPoint slides] Retrieved from: https://nararenewables.org/documents/2016/09/stakeholder-perceptions-of-jet-fuel.pdf/

60. Neuling U. and M. Kaltschmitt (2015), Conversion routes for production of biokerosene: status and assessment, *Biomass Conversion and Biorefinery*, 5:367-385.

61. Pearce, B. (2020, April 14), COVID-19 updated impact assessment, IATA. [PowerPoint slides] Retrieved from: https://www.iata.org/en/iata-repository/publications/economic-reports/covid-fourth-impact-assessment/

62. Penner J.E., Lister D.H., Griggs D.J., Dokken D.J., and M. McFarland (eds.) (1999), *Aviation and the Global Atmosphere: A special report of the Intergovernmental Panel on Climate Change*, UK: Cambridge University Press.

63. Piera, A.J. (2015), *Greenhouse gas emissions from international aviation: legal and policy challenges*, The Hague: Eleven International Publishing.

64. Rains T., Winter S.R., Rice S., Milner M.N. and Z. Bledsaw (2017), Biofuel and commercial aviation: will consumers pay more for it? *International Journal of Sustainable Aviation*, 3(3) :217-232.

65. Ramlo, S. (2016), Mixed method lessons learned from 80 years of Q Methodology, *Journal of Mixed Methods Research*, 10(1):28-45.

66. Reynolds, C. (2020, January 19), Canadian airlines feel the pressure on flight shaming and the “Greta effect”, Global News Canada. Retrieved from: https://globalnews.ca/news/6433333/canadian-airlines-feel-the-pressure-of-flight-shaming-and-the-greta-effect/

67. Roe, E. (1994), *Narrative Policy Analysis: Theory and Practice*, Durham/London: Duke University Press.

68. Roland Berger (2017), Aircraft electrical propulsion: the next chapter of aviation? Retrieved from: https://www.rolandberger.com/zh/Publications/New-developments-in-aircraft-electrical-propulsion.html

69. Seber G., Malina R., Pearlson M.N., Olcay H., Hileman J.I. and S.R.H. Barrett (2014), Environmental and economic assessment of producing Hydroprocessed jet and diesel fuel from waste oils and tallow, *Biomass and Bioenergy*, 67:108-118.

70. Smith P.M., Gaffney M.J., Shi W., Hoard S., Ibarrola Armendariz I. and D.W. Mueller (2017), Drivers and barriers to the adoption and diffusion of sustainable jet fuel (SJF) in the U.S. Pacific Northwest, *Journal of Air Transport Management*, 58:113-124.

71. Sneegas G., Beckner S., Brannstrom C., Jepson W., Lee K. and L. Seghezzo (2021), Using Q-methodology in environmental sustainability research: a bibliometric analysis and systematic review, *Ecological Economics*, 180:1-14.

72. Sneegas, G. (2019), Making the case for critical Q methodology, *The Professional Geographer*, 72(1) :78-87.

73. Soria Baledón M. and N. Kosoy (2018), “Problematizing” carbon emissions from international aviation and the role of alternative jet fuels in meeting ICAO’s aspirational goals, *Journal of Air Transport Management*, 71:130-137.

74. Söderberg M.W. and N. Wormbs (2019), *Grounded: Beyond flygskam*, Stockholm: Fores/ELF.

75. Stainton Rogers, R. (1995), Q methodology, in Smith J.A., Harré R. and L. Van Langenhofe (eds.), *Rethinking methods in psychology*, London: Sage, pp.178-192.

76. Staples M.D., Malina R., Suresh P., Hileman J.I. and S.R.H. Barrett (2018), Aviation CO_2 emissions reductions from the use of alternative jet fuels, *Energy Policy*, 114(C) :342-354.

77. Stephenson, W. (1953), *The study of behavior; Q-technique and its methodology*, Chicago: University of Chicago Press.

78. Timmis, A. (2015), A stakeholder approach to sustainable development in UK aviation, Sheffield University Management School. [Doctoral dissertation]

79. Transport & Environment (2020, July 16), Bailout tracker. Retrieved from: https://www.transportenvironment.org/what-we-do/flying-and-climate-change/bailout-tracker

80. van Eeten, M.J.G. (2017), Narrative policy analysis, in Fisher F., Miller G.J. and M.S. Sidney (eds.), *Handbook of public policy analysis: Theory, politics and methods*, Newark: Routledge, pp. 251-269.

81. van Eeten, M.J.G. (1999), *Dialogues of the Deaf: Defining new agendas for environmental deadlocks*, Delft: EBURON Publishers.

82. Watts, S. and P. Stenner (2012), *Doing Q methodological research. Theory, method and interpretation*, London: SAGE Publications Ltd.

83. WBG (2020), *Air transport annual report 2019*, Washington D.C.: World Bank Group.

84. WEF (2020), Clean Skies for Tomorrow: Sustainable Aviation Fuels as a pathway to net-zero aviation. Retrieved from: http://www3.weforum.org/docs/WEF_Clean_Skies_Tomorrow_SAF_Analytics_2020.pdf

85. Xu, N. (2020, June 9), To bail out or not: Governments decide whether to aid Asia's embattled airlines, Fortune. Retrieved from: https://fortune.com/2020/06/09/government-airline-bailout/

Regulations, documents, resolutions, working papers and information papers:

International Civil Aviation Organization (ICAO)

86. 40th Assembly Resolution A40-19: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), October 2019. Retrieved from: https://www.icao.int/environmental-protection/Documents/Assembly/Resolution_A40-19_CORSIA.pdf

87. 40th Assembly Resolution A40-18: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Climate change, October 2019. Retrieved from: https://www.icao.int/environmental-protection/Documents/Assembly/Resolution_A40-18_Climate_Change.pdf

88. 39th Assembly Resolution A39–3: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Global Market-based Measure (MBM) scheme, October 2016. Retrieved from: https://www.icao.int/environmental-protection/Documents/Resolution_A39_3.pdf

89. 37th Assembly Resolution A37–19: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Climate change, October 2010. Retrieved from: https://www.icao.int/environmental-protection/37thAssembly/A37_Res19_en.pdf

90. ICAO global environmental trends – present and future aircraft noise and emissions, A40-WP/54 [Presented by ICAO], 05/07/19. Retrieved from: https://www.icao.int/Meetings/a40/Documents/WP/wp_054_en.pdf

91. Increased transparency in ICAO decision making, A39-WP/208 [Information paper presented by the International Coalition for Sustainable Aviation (ICSA)], 18/08/16. Retrieved from: https://www.icao.int/Meetings/a39/Documents/WP/wp_208_en.pdf

92. Appendix. Declaration of the Second Conference on Aviation and Alternative Fuels, CAAF/2-SD3. 13/10/2017. Retrieved from: https://www.icao.int/Meetings/CAAF2/Documents/CAAF2%20SD%20day%203.Final.pdf

93. Definitions. CAAF/2-WP/03. 24/07/17. Retrieved from: https://www.icao.int/Meetings/CAAF2/Documents/CAAF.2.WP.003.1.en.pdf

European Commission

94. Revision of the EU Emission Trading System Directive 2003/87/EC concerning aviation, IIA-Ares(2020)3515933. 03/07/2020. Retrieved from: https://ec.europa.eu/clima/policies/transport/aviation_en

95. ReFuelEU Aviation – Sustainable Aviation Fuels, IIA-Ares(2020)1725215. 24/03/2020. Retrieved from: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12303-ReFuelEU-Aviation-Sustainable-Aviation-Fuels

ASTM International standards.

96. ASTM D7566, 2020b (2009), Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons, West Conshohocken: ASTM International. Retrieved from: http://www.astm.org.

Appendices

Table A1. Q-sort statements with their corresponding factor arrays

Item	Statement	F1	F2	F3	F4
Q01	Air travel facilitates face-to-face contact, which is desirable and necessary for the establishment and maintenance of social, economic and political linkages.	3	3	1	-3
Q02	The shift from air travel towards less environmental harmful modes of transportation will only stand a chance once airfares fully incorporate the true environmental costs of air transport.	-1	0	1	-3
Q03	The multiple roles played by governments worldwide in the civil aviation sector hinder its capacity to grow sustainably.	-2	1	-2	-2
Q04	The rapidly-growing demand for mobility simply cannot be accommodated in any sustainable way. Absolute CO_2 emissions will continue to rise.	-3	-3	-1	1
Q05	Taking at least one international holiday each year, increasingly to long-haul destinations, has turned from an aspiration to an expectation.	0	1	-1	-2
Q06	Governments and the aviation industry are heavily investing in R&D in order to break away from the current technological lock-in around fossil jet and alternative drop-in fuels.	0	-1	-3	1
Q07	No State seems to be ready for any substantial sacrifices in the economy or level of employment to protect the environment.	-1	0	0	2
Q08	Short-haul flights should be substituted for by lower-carbon modes of transportation to the largest degree possible.	0	2	1	-1
Q09	Resilience of the international aviation sector results from a very robust air travel demand, particularly from business users. Regulatory measures will not disrupt that demand unless prices would substantially increase.	2	2	2	3
Q10	The international aviation community has historically downplayed the sector's environmental impacts while overemphasizing the technological efficiencies introduced over the years.	0	-1	0	-1
Q11	Aircraft and engine design are more or less perfected technologies.	-2	-1	-3	3
Q12	The aviation sector has the responsibility to inform travelers about the environmental impacts of air transport and tourism, and to raise awareness about their options for travelling more sustainably.	0	2	0	-2
Q13	Aircraft design is conservative and risk averse to radical change.	1	0	0	-3

Item	Statement	F1	F2	F3	F4
Q14	ICAO's determination to downplay aviation's contribution to global GHGs emissions has made it much more difficult for its Member States to understand the urgency to act.	-2	0	-1	-1
Q15	Even if existing economic barriers are removed, alternative fuels are unlikely to become available in sufficient quantities to play a significant role in reducing GHGs emissions from international aviation.	-3	-3	3	-1
Q16	Hypermobility, particularly for business travel, should be acknowledged as a policy issue and addressed within aviation's climate action discussions.	0	1	2	1
Q17	Since international aviation's growth will mainly take place in developing countries, they should comply with climate change obligations in the same way developed countries are obliged to.	0	0	-1	0
Q18	There is little awareness and understanding within the aviation sector of the potential environmental impacts and externalities of air transport activities beyond fuel usage.	-2	0	-2	0
Q19	Users of air travel services experience the benefits of aviation but remain largely unaware of its negative environmental impacts.	1	0	0	1
Q20	There is no indication that alternative fuels will be available in sufficient quantities at competitive prices to meet the total aviation jet fuel requirements for attaining the CO_2 reduction goals by 2050.	1	-3	2	0
Q21	Without legal and policy frameworks suitable to address the current and future challenges imposed by climate change, the international aviation sector will be unable to reduce its CO_2 emissions to attain its climate goals.	2	0	0	1
Q22	A better understanding of alternative jet fuels' potential to reduce GHGs emissions is needed for more informed decision-making within the international aviation community and ICAO's Member States.	1	1	2	-2
Q23	Flexibility in cost structures allows airlines to accommodate fuel cost volatility.	0	-2	-2	-1
Q24	Participation of civil society in climate change discussions and the formulation of environmental policy within ICAO - and within certain of its Member States - is highly exclusive and restrictive.	-1	-1	1	0
Q25	Alternative jet fuels have the potential to reduce the radiative effect of atmospheric aircraft contrails and contrail-induced cirrus clouds as a result of cleaner combustion than conventional Jet A/A-1 fuels.	1	0	0	-3
Q26	Market distortions exist in international aviation even in the absence of environmental obligations.	2	1	1	1

Item	Statement	F1	F2	F3	F4
Q27	Little involvement of Member States from developing countries in ICAO's technical work has and will continue to create disagreement for decision-making the moment it reaches the political arena.	0	-1	0	-1
Q28	Alternative jet fuels certified under ASTM Int.'s D7566 or an equivalent standard are safe to use in aircraft and in all conventional Jet A/A-1 fueling infrastructure.	3	3	1	3
Q29	ICAO's MBM may hinder the development and adoption of net emissions reduction measures, both operational and technological.	0	-2	0	-2
Q30	Making Action Plans mandatory and auditable by ICAO will facilitate compliance by Member States with the global MBM scheme.	1	2	1	-1
Q31	Alternative jet fuels should only be considered sustainable if they demonstrate compliance with the social, environmental and economic requirements of third-party certifiers.	2	3	3	3
Q32	Business air travel remains largely overlooked and unregulated despite of its significantly larger environmental impact per capita compared to commercial air travel.	1	-1	1	-1
Q33	The CO_2 mitigation potential of alternative jet fuels is reliant on the net emission reductions from biomass production, fuel refining and transportation for delivery to the end-user.	3	2	3	3
Q34	ICAO's MBM is a tool to induce coordination among different regimes, avoid additional market distortions and shield the international aviation industry from additional financial burdens and redundant compliance.	0	2	3	2
Q35	Large-scale production of alternative jet fuels can aggravate the direct and indirect environmental impacts linked to intensive agriculture of dedicated bioenergy feedstocks (i.e. crops, lignocellulosic biomass, algae).	1	0	-1	0
Q36	The Chicago Convention does not provide anymore an appropriate framework to address the current and emerging challenges posed by climate change.	0	-1	-1	0
Q37	Future growth in demand for air travel will outpace the technological and operational efforts to reduce international aviation's contribution to climate change.	-1	-2	1	2
Q38	The distinction of edible and non-edible crops as feedstock for alternative jet fuels does not address the issue of land use, as renewable fuels made from non-edible crops - including cellulosic species - can displace forests, grazing land or directly compete with agricultural land for food production.	2	0	0	0
Q39	Production of alternative jet fuels does not have demonstrable social spillovers, as the required economies of scale prevent subsistence-to-medium farming operations to participate.	-2	-2	-1	0

Item	Statement	F1	F2	F3	F4
Q40	The 2008's steep increase in world food prices was a multifactorial crisis that was the result of severe drought, high oil prices, financial speculation in grains and the expansion of ethanol production in the US. Alternative fuels' production from edible crops cannot be blamed alone as the basis of food scarcity, as it is also the result of distributive inequality.	3	1	2	0
Q41	Emerging bioenergy feedstocks are preferred over the edible and non-edible agronomic crops despite of the prevailing knowledge gaps on their potential environmental impacts, including indirect land use changes, risks of biological invasion, biodiversity loss, etc.	-1	1	0	0
Q42	Third-party certification frameworks (i.e. RSB) lack more robust data to completely inform decision-making on the sustainability of alternative jet fuels.	-2	-2	-3	0
Q43	If airfares were to reflect the true environmental costs of flying, air travel would become inaccessible to millions since they would be at least two to three times higher than they are at present.	-1	-2	-2	2
Q44	Although alternative jet fuels can be produced from different type of "residues" (i.e. agricultural, municipal and industrial), their supply chains are not yet established to make them cost-competitive.	1	-1	0	0
Q45	World refining capacity of alternative jet fuels is constrained by economic barriers, policy uncertainty and technological limitations throughout the whole supply chain that deter investment to move production into the commercial stage.	2	2	2	1
Q46	No alternative fuel can be called a biofuel since every stage in the supply chains of biomass and fuel production involves fossil fuel inputs: petroleum-derived fertilizers, herbicides and pesticides, mechanical harvesting and several stages of fuel refining and transportation.	-3	-2	-3	-1
Q47	Virtually all carbon capture or carbon reduction schemes *are* certified. The problem is that many sustainability certification arrangements are farcical. They are institutional lies, established to allow greedy people to exploit honest people and the world's desire for climate change action. Having valid sustainability certification criteria and processes would address this issue.	-1	1	-1	-3
Q48	The use of certain types of residual materials for alternative jet fuel production can create significant market distortions and externalities. For example, used cooking oil (UCO) has become a pricey commodity traded at US$400 per tonne, perpetuating wasteful food processing techniques of edible oils.	-1	0	-1	1

Item	Statement	F1	F2	F3	F4
Q49	Preference by the international aviation community for non-edible bioenergy crops and residual materials as feedstocks for alternative jet fuels is essentially political and does not have solid scientific foundations.	-2	-1	-2	1
Q50	Responsible and sustainable sourcing of a small batch of alternative jet fuel for a single flight is commendable. Finding sufficient land to supply a sizeable portion of the present and future world's jet fuel use is a different matter.	-1	3	3	2
Q51	Air transport users are generally unaware of the advantages and drawbacks of alternative jet fuels. Since social acceptance may affect a technology's market success, public understanding of alternative fuel technology use in aviation should be pursued.	3	3	2	2
Q52	Current R&D efforts should steer towards fully-electric aircraft and away from drop-in alternative jet fuels.	-3	-3	-3	-2
Q53	Certification of renewable/green diesel as a blending component of fossil jet fuel under ASTM Int.'s D7566 and equivalent standards can significantly increase the participation of alternative fuels in meeting the industry's CO_2 reductions targets for 2020 and 2050.	2	1	-2	2
Q54	Most types of residual materials require extensive pre-treatment due to their poor quality, cancelling the environmental benefits of using them as feedstocks for alternative jet fuels' production.	-3	-3	-2	-2

Table A2. Statements showing overarching consensus among stakeholders

Item	Statement
Q01	Air travel facilitates face-to-face contact, which is desirable and necessary for the establishment and maintenance of social, economic and political linkages.
Q09	Resilience of the international aviation sector results from a very robust air travel demand, particularly from business users. Regulatory measures will not disrupt that demand unless prices would substantially increase.
Q26	Market distortions exist in international aviation even in the absence of environmental obligations.
Q28	Alternative jet fuels certified under ASTM Int.'s D7566 or an equivalent standard are safe to use in aircraft and in all conventional Jet A/A-1 fueling infrastructure.
Q30	Making Action Plans mandatory and auditable by ICAO will facilitate compliance by Member States with the global MBM scheme.
Q31	Alternative jet fuels should only be considered sustainable if they demonstrate compliance with the social, environmental and economic requirements of third-party certifiers.
Q33	The CO_2 mitigation potential of alternative jet fuels is reliant on the net emission reductions from biomass production, fuel refining and transportation for delivery to the end-user.
Q40	The 2008's steep increase in world food prices was a multifactorial crisis that was the result of severe drought, high oil prices, financial speculation in grains and the expansion of ethanol production in the US. Alternative fuels' production from edible crops cannot be blamed alone as the basis of food scarcity, as it is also the result of distributive inequality.
Q45	World refining capacity of alternative jet fuels is constrained by economic barriers, policy uncertainty and technological limitations throughout the whole supply chain that deter investment to move production into the commercial stage.
Q51	Air transport users are generally unaware of the advantages and drawbacks of alternative jet fuels. Since social acceptance may affect a technology’s market success, public understanding of alternative fuel technology use in aviation should be pursued.
Q52	Current R&D efforts should steer towards fully-electric aircraft and away from drop-in alternative jet fuels.
Q54	Most types of residual materials require extensive pre-treatment due to their poor quality, cancelling the environmental benefits of using them as feedstocks for alternative jet fuels' production.

Foreword to the Canadian case study (chapters 5 and 6)

The preceding chapters have highlighted the variety of repercussions on people and the environment emerging from engrained discursive and non-discursive practices within the air transport sector internationally. The Canadian case is no different, where a limited access to information – unless conducting research from within – is abiding.

Chapters 5 and 6 were written by the author of this thesis while employed at GARDN for the purpose of replicating some of her research, and to inform future policies and initiatives on AJF within the context of a national jurisdiction. Although greater access to information and stakeholders entailed some restrictions to academic freedom (i.e. final methodological design, scope, writing style), the research findings originally presented as reports were peer-reviewed externally and approved for public release.

The fifth chapter centers on the role for AJF in the Canadian context by presenting an updated version of the research conducted between 2017-2019, to develop the Pan-Canadian Sustainable Aviation Fuels Initiative (SAFI Canada); a national AJF roadmap that builds on the decade-long experience of the Canadian aerospace sector in actively engaging its stakeholders into collaborative projects and initiatives. This chapter discusses the accomplishments, the ongoing efforts and the gaps concerning the development of AJF in Canada by focusing on current and proposed policies and regulations.

Full authorship of chapter 5 as presented here corresponds to Mónica Soria Baledón, excepting the conceptual design of SAFI Canada, its visuals and the set of policy recommendations included in section 5.5 (The Pan-Canadian Sustainable Aviation Fuels Initiative – SAFI Canada).

Accordingly, section 5.5 was written solely by Mónica Soria Baledón (including tables and figures) but collectively conceived by Kateryna Derkach, Elvire Avalle and Malek Kacem – all of them affiliated to GARDN, who co-authored a larger institutional report commissioned by

Environment and Climate Change Canada (ECCC) and published by GARDN in 2019 on the status of AJF nationally.

This report was published as Derkach K., Soria Baledón M., Avalle E. and M. Kacem (2019), Sustainable aviation fuels: a Canadian Perspective. Report prepared by GARDN for ECCC, Montreal. Available at: https://safcommunity.org/page/white-paper

5

What role for AJF in Canada? A stakeholder's approach

5.1. Aerospace pioneers

Fifteen years ago, Canada was among the first countries to voluntarily set environmental targets to reduce the carbon footprint of commercial aviation and to pioneer collaborative research into the development of alternative jet fuels (AJF). Ongoing efforts to reduce greenhouse gas (GHG) emissions from the air transport sector at the federal and provincial levels include a variety of regulatory and policy instruments that, if addressed comprehensively, could support the development of a Canadian AJF industry (ECCC 2020).

Since 2010, the demand for air transport services in Canada has grown steadily and, despite the annual fuel efficiency gains from enhanced technologies, operations and navigation, the total GHG emissions have also increased (TC 2019). Between 2005 to 2018, GHG emissions from domestic and international aviation increased by 76.6% from 12.62 to 22.04 $MtCO_2e$ (TC 2016, 2018, 2019); an upward trend expected to resume as demand for air traffic gradually recovers from the global impact brough about by the SARS-CoV-2 pandemic[1] (also known as COVID-19) (Snoddon et al. 2020; ATAG 2020a; A39-WP/55).

Climate targets from domestic aviation are governed by Canada's commitments under the Paris Agreement to reduce in 30% its GHG emissions by 2030 compared to 2005 levels. International targets follow those set in 2009 by the International Air Transport Association (IATA), consisting of: (1) increasing the annual average fuel efficiency by 1.5%, (2) achieving carbon-neutral growth from 2020 and (3) halving the sector's emissions by 2050 compared to 2005 levels. The use of alternative jet fuels (AJF) could support the Canadian aviation sector to meet its domestic and

[1] In February 2020, the load factor in Canada averaged 83%, bottoming out at 26% in April 2020 following the global travel restrictions to contain the spread of the virus (Snoddon et al. 2020).

international emissions reduction targets (ECCC 2020; Govt. of Canada 2016), but there is presently no domestic production of these fuels at the commercial scale[2].

The lack of dedicated policies and harmonized regulations has been recurrently cited in the literature as the major contributor to shortfalls in global production of AJF (ATAG 2020b; ICAO 2019; Deane and Pye 2018; Bosch et al. 2017), where an increasing number of studies have analyzed the role of stakeholders in decision-making processes (Soria Baledón et al. 2021; Smith et al. 2017; DOE 2017; Filimonau and Högström 2017; Rains et al. 2017; Gazis et al. 2016; Timmis 2015; NARA 2015; Gegg et al. 2015 and 2014).

This chapter compiles and updates part of the research work conducted by the author while employed by the Green Aviation Research and Development Network[3] (GARDN) and published elsewhere[4]; conductive to envision a national alternative aviation fuel roadmap that builds on the decade-long experience of the Canadian air transport sector in actively engaging its stakeholders into the policy-making process.

The roadmap, known as the Pan-Canadian Sustainable Aviation Fuels Initiative (SAFI Canada), focuses on the development of supply chains for accelerating the commercialization and availability of Canadian-made alternative jet fuels. There are six strategic areas that form the basis of SAFI Canada: (1) research, development and demonstration (RD&D) and innovation, (2) financing and strategic partnerships, (3) policy and regulations, (4) technical and sustainability certifications, (5) outreach and knowledge transfer, and (6) consortia-building and regional initiatives.

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[2] In 2018, Transport Canada reported a consumption by Canadian air carriers of 8.5 billion litres of conventional aviation fuel (CAF) (TC 2019).

[3] GARDN is a not-for-profit organization primarily funded by the Business-Led Network of Centres of Excellence (BL-NCE) of the Government of Canada and the Canadian aerospace industry. GARND's mission is to reduce the industry's environmental footprint by developing technologies and processes for a quiet, clean and sustainable aerospace sector.

[4] Derkach K., Soria Baledón M., Avalle E. and M. Kacem (2019), Sustainable aviation fuels: a Canadian Perspective. Report prepared by GARDN for Environment and Climate Change Canada (ECCC), Montreal. Available at: https://safcommunity.org/page/white-paper.

The objective of this chapter is to provide an overview of the accomplishments, the ongoing efforts and the gaps concerning the development of alternative jet fuels in Canada – with an emphasis in policies and regulations; and to propose recommendations for each of the aforementioned strategic areas that can contribute to operationalize the objectives of SAFI Canada.

5.2. Methods

The information and data collected for the elaboration of the report prepared by GARDN[5] were obtained from primary and secondary sources. Primary sources included surveys, external consultations and personal communications[6] with stakeholders within GARDN's network and with those identified through a stakeholders mapping exercise[7] conducted in 2018 (Soria Baledón 2018).

Secondary sources included electronic media articles, reports and publications from authoritative international organizations, conference proceedings, etc., as well as a wide array of documents from GARDN's internal archives, including research project reports.

A survey consisting of a semi-structured questionnaire of 28 items (view Appendix) was distributed via GARDN's SAF Community platform[8]. The survey was available in English and French, and responses were received between January 8 and 21, 2019. Participation was optional and responses could be submitted anonymously. The survey was sent to 650 individuals and organizations, from which GARDN received 61 responses.

Participating stakeholders encompassed airlines, airports, academia, consulting firms, certification bodies, feedstock producers and suppliers, investors, financial institutions, original equipment

[5] Ibid.
[6] Data collection was conducted by GARDN; therefore, participants' information is confidentially stored within the organization's archives and not with the author.
[7] Chapter 6 presents an updated and extended version of the project's report.
[8] www.safcommunity.org is a dedicated online platform for gathering and engaging stakeholders in AJF-related projects and initiatives taking place within Canada. The platform also serves as a knowledge repository accessible to the general public at no cost.

manufacturers (OEMs), R&D centres, industrial associations, consortia, and provincial and federal government departments.

Data collection and analysis were followed by telephonic consultations with an advisory panel consisting of Canadian and international experts and stakeholders within the air transport community.

5.3. Laying the foundations for a Canadian AJF industry

Over the past decade, five project-specific consortia were created through GARDN programs to set the foundations for the development of Canadian-based supply chains for alternative jet fuels (Fig.5.1). Overall, these projects have created a community of interest and they have been essential to understand the obstacles and the opportunities for the commercial deployment of AJF in Canada[9].

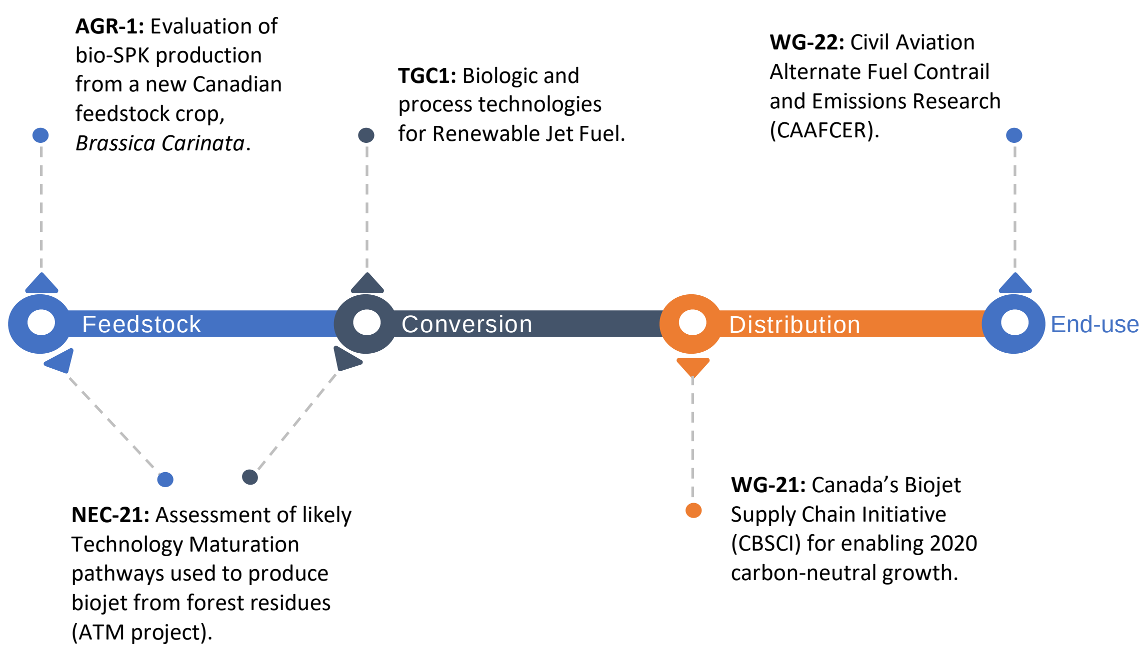

Figure 5.1. GARDN projects on AJF

[9] For a detailed description of these projects, see Derkach et al. (2019).

The first two projects undertaken by GARDN, AGR-1 and TGC-1 (Fig.5.1), aimed at assessing the viability of producing AJF from oilseed crops (i.e. *camelina sativa* and *brassica carinata*) via the hydrotreatment of esters and fatty acids (HEFA-SPK). These projects also evaluated the efficiencies in the conversion, the combustion and the performance of the resulting fuel, so as the effects on emissions and particulate matter from using AJF compared to conventional aviation fuel (CAF) (GARDN 2012).

The remarkable achievements of AGR-1 and TGC-1, including the world's first flight using 100% neat[10] AJF and the first Canadian revenue flight using a 50/50 AJF blend, opened the way to further research into the effects of AJF[11] on atmospheric contrail formation (WG-22), and into thermochemical processes (i.e. catalytic pyrolysis, fast pyrolysis and hydrothermal liquefaction) to produce AJF from lignocellulosic biomass (NEC-21) (Fig.5.1). Whereas the conversion technologies analyzed in project NEC-21 are still under development or at demonstration scale, the long-term viability of AJF supply chains across Canada will be primarily reliant on the utilization of lignocellulosic feedstocks such as forestry and agricultural residues compared to other feedstock sources (van Dyk et al. 2019).

In 2018, the Canada's Biojet Supply Chain Initiative (CBSCI/WG-21) (Fig.5.1) introduced a 30/70 AJF blend into the existing infrastructure at Toronto's Lester B. Pearson International Airport (YYZ); demonstrating the operational feasibility of supplying AJF to Canadian airports while providing stakeholders with operational experience in the handling of alternative fuels (CBSCI 2019a).

The initiative comprised a total of 14 national and international stakeholders for supplying 230,000 litres of certified[12] AJF to 22 domestic flights operated by Air Canada. In commemoration of Earth's Day, the flights departed from Toronto on April 22, 2018, resulting in GHG reductions of approximately 161.6 tonnes $CO_{2}e$ (CBSCI 2019a).

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[10] ASTM D7566 mandates a maximum blend of 50 percent AJF with petroleum-based jet fuel (CAF), except for the HFS-SIP conversion pathway that has a blending ceiling of 10 percent (ASTM D7566-20b).
[11] The WG-22 project conducted flight measurements using a 43/57 HEFA-SPK blend (Brown et al. 2018).
[12] The 30/70 HEFA-SPK blend supplied by AltAir, today World Energy, was compliant with ASTM D7566 and with the RSB Global Fuel Certification (CBSCI 2019b).

The CBSCI set a milestone for the development of a Canadian AJF industry due to is comprehensive approach and contributions to the six strategic areas that conform SAFI Canada. Compared to the GARDN projects on AJF that preceded the CBSCI, the latter included an important knowledge transfer and outreach component to document and disseminate the results and best practices through the use of social-media platforms (i.e. Twitter, YouTube, LinkedIn) and a dedicated website[13] where the technical and policy reports were published.

The outreach strategy of the CBSCI had relevant spillovers for policy-making insofar the initiative's success was shortly followed by other initiatives at the federal (e.g. The Sky's the Limit Challenge) and provincial levels (e.g. Alberta Biojet Initiative, BioPortYVR) that have targeted prevailing gaps along different components of the AJF supply chain[14].

Furthermore, the implementation of the CBSCI has raised public awareness about the role of alternative jet fuels in reducing the environmental impact of aviation, and it has prompted an increasing number of stakeholders to actively engage in the decision-making processes and discussions to make AJF eligible as a compliance pathway under federal and provincial regulations.

5.4. A climate action framework for Canadian aviation

Canada's efforts to reduce its GHG emissions from the aviation sector date back to 2005, when Transport Canada and the Air Transport Association of Canada (ATAC) signed a voluntary agreement to annually improve by 1.1% increments through to 2020, the average fuel efficiency from domestic and international aviation compared to 1990 levels (TC 2012).

In 2009, this agreement was followed by two major international landmarks: (1) the ratification of the Copenhagen Accord in which Canada committed to reducing its national GHG emissions by 17% by 2020 compared to a 2005 baseline (Environment Canada 2011), and (2) the setting of carbon reduction targets for international aviation by the International Air Transport Association

[13] www.cbsci.ca and www.biojet.ca
[14] The Sky's the Limit Challenge and BioPortYVR are discussed in detail in chapter 6.

(IATA), two of which were endorsed in 2010 by the International Civil Aviation Organization (ICAO) at its 37th Assembly[15] (ICAO 2014; ATAG 2012).

These national and international commitments were incorporated into *Canada's Action Plan to Reduce Greenhouse Gas Emissions from Aviation*[16], a federal initiative submitted in 2012 by the Government of Canada in fulfillment of ICAO's 37th Assembly resolution A37-19. The Action Plan increased the original annual fuel efficiency target of 1.1% to 2% through 2020 compared to 2005 levels and incorporated a set of operational and technological measures to address carbon emissions from both domestic and international aviation activities.

Although GARDN had been conducting extensive research on alternative jet fuels for nearly half a decade already, the Action Plan was the first policy document to acknowledge the role of AJF in reducing aviation's emissions and to financially support research and development activities. Federal programs at the time included the ecoENERGY Innovation Initiative, the Program of Energy Research and Development, the SD Tech Fund™ and the NextGen Biofuels Fund™.

Following the signing of the Paris Agreement in 2015, the Government of Canada updated its national target to reduce GHG emissions in 30% by 2030 compared to 2005 levels as part of its climate commitment to limit global warming to 1.5°C above pre-industrial levels (Govt. of Canada 2017). This target has been foundational to the Pan-Canadian Framework on Clean Growth and Climate Change (PCF) launched in 2016, a country-wide approach based on pricing carbon pollution for transitioning to a low-carbon economy.

[15] The targets consist of: (1) increasing the annual average fuel efficiency by 1.5%, (2) achieving carbon-neutral growth by 2020 and (3) halving the sector's emissions by 2050 compared to 2005 levels. Whereas the ICAO Assembly has had a decade-long mandate to explore the feasibility of a long-term climate goal for international aviation (A37-19), only the targets for fuel efficiency (set at 2%) and carbon-neutral growth were endorsed by the ICAO.

[16] From now on referred to as "the Action Plan".

5.4.1. Policy efforts and gaps on AJF

The use of low-carbon and renewable fuels in Canada has been mandated by federal and provincial regulations[17] since 2010 (SOR/2010-189), but their subsequent revisions have failed to incorporate AJF despite the approval by ASTM International of several conversion pathways since 2009 (ASTM D7566-20b). In consequence, the mandates applicable to gasoline and diesel blends have created domestic markets for alternative fuels in the road transport sector, yet the development of AJF in Canada has been precluded from reaching the commercial scale.

The PCF acknowledges the prevailing technological limitations to power aircraft with renewable energies other than liquid fuels and it is recognizant of the potential of AJF for achieving greater GHG emission reductions than those attained thus far through improved navigation and operations (Govt. of Canada 2016). However, the measures proposed in the PCF to price pollution do not individually provide a competitive advantage to AJF against other low-carbon fuels that can also be used to comply with the existing regulations (e.g. renewable diesel).

At present, there are no long-term programs, incentives or regulations for AJF, other than those already mentioned above, that are equivalent to the incentives set in place for low-carbon and advanced fuels for the road transport sector. Furthermore, most federal and provincial programs that support research and development activities on AJF have either expired or are set to expire post-2022. This is a largely unrecognized factor despite that domestic air travel, like road transport, falls within the category of domestic emissions for climate target-setting purposes.

The lack of a comprehensive and dedicated framework at the federal and the provincial levels was identified by the participants to the GARDN study[18] as the main obstacle to attract investment for scaling up AJF production in Canada. Despite the valuable contributions of the demonstration and the commercialization initiatives launched over the past decade, participants also acknowledged that these will not, by themselves, drive the development of a Canadian AJF industry.

[17] See Soria Baledón (2017) for an analysis on scope, applicability and points of compliance. The Renewable Fuels Regulations (RFR) will be repealed in 2023 and the mandated renewable fuel content in gasoline and diesel will be incorporated in Clean Fuel Standard (CFS).
[18] See Derkach et al. 2019 for details.

5.4.2. "The backstop": a pan-Canadian carbon levy

The Greenhouse Gas Pollution Pricing Act (GGPPA) adopted in June 2018, introduced a carbon-pricing system ("the backstop") in provinces and territories that fell below the minimum federal requirements[19]. The GGPPA covers GHG emissions from aviation in all the backstop provinces but not in the territories[20].

The carbon tax came into effect in April 2019 in Saskatchewan, Manitoba, Ontario and New Brunswick[21]; in January 2020 in Alberta[22], and it is applicable to CAF used in intra-provincial flights[23]. Table 5.1 presents the CAF charge rates applicable under the GGPPA:

Table 5.1. Carbon levy applicable to the backstop provinces

	04/2019-03/2020	**04/2020-03/2021**	**04/2021-03/2022**	**Beginning 04/2022**
Charging rate ($/tonne CO_2e)	20	30	40	50
CAF charging rate ($/L)	0.0516	0.0775	0.1033	0.1291

Source: CRA (2020b), Fuel Rate Charges. Retrieved from: https://www.canada.ca/en/revenue-agency/services/forms-publications/publications/fcrates/fuel-charge-rates.html

The introduction of the GGPPA presents a number of challenges for the near-term development of AJF in Canada. First, the differences between the backstop provinces and those with existing carbon-pricing systems on CAF do not address the potential financial impacts of intra- and inter-provincial flights, which could disproportionately damage local air carriers and airports.

Second, unlike alternative fuels for road transport that are blended above the mandated levels (e.g. ethanol, biodiesel and renewable diesel), AJF are not exempt from the federal and provincial

[19] The GGPPA also introduced a regulatory system for large industries known as the output-based pricing system (OBPS).
[20] Due to the high cost of living, the existing challenges with food security and the high reliance on air transport, the Yukon, Nunavut and the Northwest Territories are exempt from the carbon levy on CAF.
[21] Effective April 1, 2020, New Brunswick is no longer a listed province under the federal fuel charge (CRA 2020a).
[22] Alberta repealed its carbon levy in May 2019, thus joining Ontario, Manitoba and Saskatchewan in the list of jurisdictions covered by the federal fuel charge (FIN 2019).
[23] Pricing on CAF in BC will continue to raise up to $50/tonne CO_2e to meet the federal requirements by 2022.

carbon levies. Even when AJF could become eligible to generate credits under the liquid stream of the Clean Fuel Standard[24] (CFS) and potentially[25] under British Columbia's Low-Carbon Fuel Standard[26] (BC-LCFS), the carbon tax would lead to an increase in the premium on CAF, which historically sells at a discount to other conventional fuels.

To exemplify this, the techno-economic analysis (TEA) conducted for GARDN's NEC-21 project (Fig.5.1) to assess maturation pathways for AJF production from forest residues in British Columbia, showed a minimum fuel selling price (MFSP) between CAD$1,724 and $3,926 per metric tonne or CAD$1.37 and $3.11 per litre of alternative fuel[27] for the different pathways analyzed (van Dyk et al. 2019). Based on an average price per metric tonne of CAF of CAD$855.25, this represents a premium of CAD $963/Mt to reach the MFSP of the most affordable AJF conversion pathway.

The project also showed that even if the credits generated under the BC-LCFS could reduce the AJF premium to CAD $481/Mt, the provincial tax on carbon would offset this revenue by approximately CAD $98.65/Mt[28] for intra-provincial flights.

Third, the GGPPA is estimated to leverage $133M in 2019 and up to $333M in 2022 (CBSCI 2019c). However, the revenues collected are not expected to fund mitigation or adaptation measures in the aviation sector[29] despite the current financing needs to de-risk investment in AJF in Canada and support other initiatives conductive to the development of domestic supply chains.

[24] The Clean Fuel Standard will allow compliance credits to be generated as of the date of publication of the final regulations in 2021.
[25] The proposal to include AJF in the provincial regulations is currently under review as part of the CleanBC Climate Action Plan launched in December 2018.
[26] The BC-LCFS comprises the Greenhouse Gas Reduction Act and the Renewable & Low Carbon Fuel Requirements Regulation.
[27] Conversion factor of 1,260 litres of CAF per metric tonne.
[28] In March 2019, the BC carbon tax was CAD$0.0783 per litre of CAF on flights within the province. Inter-provincial and international flights are exempt from the levy.
[29] Approximately 90% of the federal revenues will be returned to residents of the backstop provinces through the Climate Action Incentive payments, whereas the remaining portion will support climate change adaptation strategies in colleges, universities, hospitals, non-profits, indigenous communities, etc.

5.4.3. Carbon intensity and the Clean Fuel Standard (CFS)

As per the CFS proposed regulatory approach presented in June 2019, low-carbon-intensity liquid fuels are expected to contribute with 23 MtCO_2e out of the aspirational reduction goal of 30 MtCO_2e by 2030 (ECCC 2019a). The CFS aims to complement the PCF's approach to carbon pricing by reducing the carbon intensity (CI) of petroleum-based fuels on a life cycle basis. The liquid stream of the CFS will enter into force in 2022, and it could allow for compliance credits for AJF to be generated as of 2021 when the final regulations are published in the *Canada Gazette*, Part II.

At present, aviation gasoline and CAF used for international flights are exempt from compliance to the CFS[30], and the inclusion of CAF for domestic aviation remains under consideration (ECCC 2019a). Parties currently obligated to follow the CFS include producers and suppliers of national and imported fuels, who will operate within a compliance market system supported by credit generation and trading.

If included in the final regulations, the CFS would require a reduction in the carbon intensity of CAF for domestic travel from 3.6g CO_2e/MJ in 2022 up to 10g CO_2e/MJ by 2030. This would be equivalent to a 10 to 12% reduction below 2016 levels as determined by Environment and Climate Change Canada's (ECCC) Fuel Life Cycle Assessment Modelling Tool[31]. The proposed interim CI value[32] for CAF is 86g CO_2e/MJ, which is more stringent than the CI value of 89g CO_2e/MJ determined by the ICAO for the phased-in implementation in 2021 of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) (ICAO 2019).

In the outcome that the CFS final regulations exempt CAF from compliance, producers and importers of AJF could still generate credits under the category of "low-carbon-intensity fuels", provided they demonstrate a CI equal or below than 90% of the credit reference CI value for CAF

[30] Canadian production of AJF and lower carbon aviation fuels (LCAF) will be eligible to fulfill the offsetting obligations of aircraft operators under CORSIA if they meet the scheme's sustainability criteria.
[31] Currently under development. It is important to note that the CI values will exclude the impacts of indirect land-use change (iLUC). Whereas measures will be adopted to protect against adverse environmental impacts, iLUC values could be incorporated in 2025 at the first CFS review.
[32] The first interim value proposed was 83g CO_2e/MJ (ECCC 2019b).

(ECCC 2019b). In this scenario, and for conversion processes that yield co-products with already established markets (e.g. renewable diesel, naphtha), the use of a multiplying factor for credit generation under the CFS could provide AJF with a competitive advantage.

According to the CFS regulatory proposal, low-carbon intensity fuels will also count towards meeting the obligations of applicable provincial regulations[33] where AJF is produced and/or supplied. This excludes producers and importers of petroleum-based fuels covered by the CFS, who will be ineligible to generate or use credits for compliance with other regulations (e.g. the GGPPA's Output-Based Pricing System [OBPS]).

5.5. The Pan-Canadian Sustainable Aviation Fuels Initiative (SAFI Canada)

The information and data collected in January 2019 from primary sources[34] were essential to comprehensively assess the prevailing obstacles and the opportunities for the development of a Canadian AJF industry over the next 5 to 10 years.

Participants were primarily affiliated to fuel production, research and development, academia, and feedstock production, some of which are currently based abroad (e.g. SkyNRG, RSB) but have been actively involved in AJF projects within Canada. Canadian stakeholders were primarily located in Ontario, Alberta, Quebec and British Columbia (Derkach et al. 2019).

The results of these consultations are summarized in Table 5.2 and organized per strategic area along each of the components of the AJF supply chain. Most importantly, the exercise allowed to envision a national AJF roadmap, named SAFI Canada, purposely designed to actively engage its stakeholders into the federal and provincial policy processes.

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[33] The BC-LCFS also has a carbon intensity approach (CI) that sets annual targets for petroleum-based fuels used in the province. The BC-LCFS comprises the Greenhouse Gas Reduction Act and the Renewable & Low Carbon Fuel Requirements Regulation.

[34] Participating stakeholders included airlines, airports, academia, consulting firms, certification bodies, feedstock producers and suppliers, investors, financial institutions, original equipment manufacturers (OEMs), R&D centres, industrial associations, consortia, and provincial and federal government departments.

Table 5.2. Gaps and challenges for AJF market development

Strategic area/component	Feedstock	Conversion	Distribution	End-use
RD&D	Development and maturation of advanced and non-conventional feedstocks[1]	Development and maturation of feedstock-agnostic conversion technologies	Optimization and testing of AJF blends that are suitable for the existing supply infrastructure	Demonstration of AJF supply using existing fuel infrastructure in airports across Canada (e.g. CBSCI)
Financing	Wider access to loans, guarantees and insurance	Access to capital grants and producer-based incentives	Development of dedicated blending infrastructure at storage terminals and tank farms	PPPs and government procurement through off-take agreements
Certification	Streamlined support for sustainability certification	Streamlined support for fuel qualification under ASTM D4054	Review of CSA B836 for blending infrastructure at airport tank farms	Monitoring, reporting and verification of compliance with the CFS and CORSIA (as applicable)
Outreach and knowledge transfer	Communicate the value proposition of AJF and actively engage stakeholders along the supply chain. Expand outreach by leveraging social-media resources (e.g. SAF Community)			
Consortia and regional initiatives	Multi-stakeholder initiatives focused on commercial-scale production and supply of AJF through bioports[2] (e.g. BioPortYVR)			
Policy and regulation	Inclusion of AJF as qualifying fuels under federal and provincial renewable fuels regulations. Progressive and phased-in federal and provincial blending mandates. Taxation of petroleum-based jet fuel based on a carbon intensity approach (CI).			

[1] Advanced feedstock materials include lignocellulosic biomass and algae. Non-conventional feedstocks are those that do not generate land use change (LUC) or indirect land use change (iLUC), such as capture and densification of atmospheric carbon dioxide, hydrogen produced using renewable energies, fungi, etc.
[2] A bioport is an integrated AJF production and distribution system located in or in the vicinity of an airport.

SAFI Canada was conceived to support and accelerate the development of a domestic industry for alternative jet fuels, with GARDN as the entity responsible for engaging and coordinating multi-stakeholder projects and initiatives though the entire fuel supply chain[35].

The roadmap is founded on the principles of eco-design, industrial symbiosis and the circular economy, and it focuses on six strategic areas (Fig.5.2): (1) research, development and demonstration (RD&D) and innovation, (2) financing and strategic partnerships, (3) policy and regulations, (4) technical and sustainability certifications, (5) outreach and knowledge transfer, and (6) consortia-building and regional initiatives.

[35] As the decade-long mandate of GARDN is set to conclude in March 2021, the organization has officially started the legal and administrative process to transition into SAFI Canada (GARDN 2020).

Based on the feedback provided by stakeholders, six objectives for SAFI Canada were defined and grouped into three main themes:

Table 5.3. Objectives pursued by SAFI Canada

Theme	No.	Objective
Innovation	1	Advance research on new feedstock sources and conversion processes
	2	Support the technical and sustainability certification processes
Facilitation	3	Mitigate public and private investments
	4	Enable and inform cross-sectoral policy development
Engagement/ connection	5	Promote knowledge transfer and outreach
	6	Establish partnerships encompassing all stakeholders along the supply chain

Figure 5.2 graphically depicts the constitutive elements of SAFI Canada as defined by GARDN:

Figure 5.2. Overview of the Pan-Canadian SAF Initiative

Specific targets for each of the objectives pursued by SAFI Canada, including a new organizational mandate, vision and mission, are yet to be defined before March 2021, following a new consultation round with GARDN's stakeholders and its community of interest.

The following recommendations summarize the key elements within each strategic area[36] to be addressed by SAFI Canada from a comprehensive, collaborative and participatory approach.

Strategic Area 1 — RD&D and innovation

- Facilitate cross-sectoral research for advanced and non-conventional feedstocks and conversion technologies for AJF production.
- Allocate public investment to collaborative RD&D projects at low Technology Readiness Levels[37] (TRL1 - TRL3).
- Set innovation strategy targets for AJF development.
- Focus RD&D efforts on the feedstock sources that are the most environmentally and economically sustainable in the long-term.
- Encourage the development of feedstock-agnostic conversion technologies.
- Investigate Canadian opportunities for co-processing and production of LCAF.

Strategic Area 2 — Financing and strategic partnerships

- Encourage federal procurement and other public incentives to finance the premium on AJF for government-related travelling.
- De-risk private and public investments with a coordinated approach between federal and provincial financial-support programs.
- Enhance access to capital grants, loan guarantees, tax credits, producer-based incentives, RD&D support programs, etc.
- Foster the production and consumption of more sustainable products and services in the air transport sector through public-private partnerships (PPPs).

[36] See Derkach et al. 2019 for a detailed analysis of each strategic area.
[37] The TRL is a method to assess the maturity of a technology and it is measured on a scale from 1 to 9.

Strategic Area 3 — Policy and regulations

- Design and implement a national AJF roadmap in support of the climate targets pursued by the PCF, the CFS and equivalent provincial regulations (BC-LCFS).
- Harmonize the carbon-pricing schemes among Canadian provinces and territories to address concerns of fair competition distortions.
- Exempt AJF from federal and provincial carbon levies to reduce the price gap with CAF.
- Re-invest CAF charge proceeds into mitigation and adaptation measures within the aviation sector.
- Allow the use of a multiplying factor (≥1.5x) for AJF to generate compliance credits under the applicable federal (e.g. CFS) and provincial regulations (e.g. BC-LCFS).
- Incorporate iLUC values into the ECCC's LCA Modelling Tool during the 2025 CFS review with the objective of minimizing the potential trade-offs from commercial deployment of AJF.
- Set "balanced commitment" targets between the industry and regulators in support of national GHG reduction goals.
- Engage stakeholders through demonstration initiatives across Canada to facilitate AJF integration into the existing transport, storage and distribution infrastructure.

Strategic Area 4 — Technical and sustainability certifications

Technical certification

- Ensure a coordinated approach to the certification of AJF from various federal departments including but not limited to the National Research Council of Canada, Transport Canada, Natural Resources Canada, National Defense, and Environment and Climate Change Canada.
- Develop a fast-track approach to the certification of AJF conversion pathways in Canada under ASTM D4054[38].
- Provide assistance to applicants throughout the fuel certification process.
- Provide incentives to support fuel testing and review processes for AJF certification.

[38] This standard provides fuel producers with guidance regarding testing and property targets required to asses a candidate AJF. The certification process comprises a four-tier approach that fuel producers need to iterate and pass for the incorporation of the candidate AJF as a drop-in synthetic fuel under the ASTM D7566 standard.

- Review the existing guidelines for incorporating AJF into the downstream logistics of CAF (API 1543, API 1595 and CSA B836).

Sustainability certification

- Develop a comprehensive LCA database for the Canadian AJF and LCAF industry to ensure data consistency throughout federal and provincial regulations and policies.
- Develop a meta-sustainability framework to ensure compliance with the already established international sustainability standards such as RSB and ISCC.
- Provide incentives to support Canadian stakeholders undergoing fuel and/or feedstock sustainability certification processes.

<u>Strategic Area 5</u> — Outreach and knowledge transfer

- Implement a communication plan to raise awareness among Canadians of the benefits of a Clean Fuel Standard, a carbon tax and other carbon-pricing policy mechanisms and their potential to reduce the environmental impact of aviation.
- Deploy a comprehensive outreach strategy to communicate the value proposition of AJF to Canadian stakeholders and to the users of air transport services in general.
- Encourage citizens, through social media and online campaigns, to reduce non-essential air travel and consider other means of transportation with lower environmental impact.
- Hold a dedicated AJF forum in Canada on an annual or biennial basis.
- Encourage knowledge transfer between regional and national initiatives via workshops and webinars.
- Have a dedicated organization to advance knowledge transfer and public awareness on AJF.

<u>Strategic Area 6</u> — Consortia-building and regional initiatives

- Encourage the development of multi-stakeholder AJF regional projects and initiatives.
- Foster network-to-network (N2N) approaches to facilitate cross-sectoral collaboration and extended knowledge transfer.

5.6. Greater policy ambition needed

Climate change entails economy-wide risks and impacts for Canada that could overlap spatially and temporally, creating new and exacerbating hazards, exposures and vulnerabilities for communities across all provinces and territories (Ecofiscal Commission 2019). Although Canada's carbon pricing scheme is set to reach CAD $50 per tonne by 2022, reaching the national emissions target for 2030 demands more stringent federal and provincial climate policies than those currently implemented and proposed.

The use of alternative jet fuels is expected to help the Canadian aviation sector to meet its emissions targets while seizing an enormous economic opportunity to mitigate some of the financial risks of climate change in Canada[39]. Over the next years, the viability of a domestic AJF industry will remain strongly tied to the regulatory framework and the policies resulting from the implementation of the Clean Fuel Standard and equivalent provincial regulations, such as the BC Low-Carbon Fuel Standard.

Despite the impact of the SARS-CoV-2 pandemic on the Canadian air transport sector, Canada faces a unique juncture for accelerating the commercial deployment of AJF through the implementation of a national roadmap (SAFI Canada) that leverages on:

1. The accomplishments and experience gained from the GARDN projects and the community of interest created thereof,
2. The international efforts on RD&D, financing and supply chain development since 2008,
3. The entry into force in all Canadian provinces (backstop jurisdictions and provinces with existing carbon-pricing systems) of a carbon levy on CAF since April 2019,
4. The entry into force of the liquid stream of the CFS in 2022,
5. The active engagement of stakeholders along the supply chain of AJF in Canada and abroad,

[39] The National Round Table on the Environment and the Economy calculated a climate change cost to Canada between CAD $21 to $43 billion per year by 2050 (Govt. of Canada 2016; NRTEE 2011).

6. The technological and business innovations achieved thus far by initiatives such as The Sky's the Limit Challenge[40], and
7. The implementation of multi-stakeholder projects such as the CBSCI that successfully encompassed the approach envisioned for SAFI Canada for building a domestic AJF production capacity.

As per the recommendations listed in section 5.5, the upcoming entry into force of dedicated carbon-pricing regulations and policy mechanisms, if properly harmonized across governments, will be key for enabling market deployment of AJF in Canada over the next half-decade.

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Declaration of interest

The author has no conflicts of interest to disclose.

[40] See chapter 6 for a detailed description of the Challenge.

Literature cited

1. ATAG (2020a), Waypoint 2050. Retrieved from: https://aviationbenefits.org/media/167187/w2050_full.pdf

2. ATAG (2020b), Aviation's energy transition. Retrieved from: https://aviationbenefits.org/downloads/fact-sheet-5-aviations-energy-transition/

3. ATAG (2012), Powering the future of flight: The six easy steps to growing a viable aviation biofuels industry. Retrieved from: http://www.atag.org/component/downloads/downloads/152.html

4. Bosch J., de Jong S.A., Hoefnagels R. and R. Slade (2017), Aviation biofuels : strategically important, technically achievable, tough to deliver, Grantham Institute, Imperial College London. Retrieved from : https://www.imperial.ac.uk/media/imperial-college/grantham-institute/public/publications/briefing-papers/BP-23-Aviation-Biofuels.pdf

5. Brown A.P., Bastian M., Femia F., Ghatala F., Olfert J., Beunis R., Valk M. and N. Gaudet (2018), Civil Aviation Alternate Fuels Contrails and Emissions Research (CAAFCER): operations and contrail observations. Report prepared by NRC for GARDN. Retrieved from: https://cbsci.ca/wp-content/uploads/CAAFCER-Operations-Report_LR-FRL-2018-0013.pdf

6. CBSCI (2019a), Canada's Biojet Supply Chain Initiative (CBSCI) Operations Report. Retrieved from: https://cbsci.ca/reports/

7. CBSCI (2019b), HEFA Production and Feedstock. Retrieved from: https://cbsci.ca/reports/

8. CBSCI (2019c). Policy Tools for Enabling Biojet. Retrieved from: https://cbsci.ca/reports/

9. CRA (2020a), FCN13 New Brunswick no longer a listed province under Part 1 of the Greenhouse Gas Pollution Pricing Act effective April 1, 2020. Retrieved from: https://www.canada.ca/en/revenue-agency/services/forms-publications/publications/fcn13/new-brunswick-no-longer-listed-province-under-part-1-greenhouse-gas-pollution-pricing-act.html

10. CRA (2020b), Fuel Rate Charges. Retrieved from: https://www.canada.ca/en/revenue-agency/services/forms-publications/publications/fcrates/fuel-charge-rates.html

11. Deane J.P. and S. Pye (2018), Europe's ambition for biofuels in aviation. A strategic review of challenges and opportunities, *Energy Strategy Reviews*, 20:1-5.

12. Derkach K., Soria Baledón M., Avalle E. and M. Kacem (2019), Sustainable aviation fuels: a Canadian Perspective. Report prepared by GARDN for Environment and Climate Change Canada (ECCC), Montreal. Available at: https://safcommunity.org/page/white-paper

13. DOE (2017), Alternative aviation fuels : overview of challenges, opportunities and next steps. Retrieved from: https://www.energy.gov/sites/prod/files/2017/03/f34/alternative_aviation_fuels_report.pdf

14. ECCC (2020), Pan-Canadian Framework on Clean Growth and Climate Change. Third annual synthesis report on the status of implementation, Gatineau. Retrieved from: http://publications.gc.ca/collections/collection_2020/eccc/En1-77-2019-eng.pdf

15. ECCC (2019a), Clean Fuel Standard: proposed regulatory approach, Gatineau. Retrieved from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/pricing-pollution/Clean-fuel-standard-proposed-regulatory-approach.pdf

16. ECCC (2019b), Regulatory Design Paper for the Clean Fuel Standard, Gatineau. Retrieved from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/clean-fuel-standard-regulatory-design-paper-2018-en-1.pdf

17. Ecofiscal Commission (2019), Bridging the gap: real options for meeting Canada's 2030 GHG target, Montreal. Retrieved from: https://ecofiscal.ca/wp-content/uploads/2019/11/Ecofiscal-Commission-Bridging-the-Gap-November-27-2019-FINAL.pdf

18. Environment Canada (2011), Canada's Emissions Trends, Gatineau. Retrieved from: https://www.ec.gc.ca/doc/publications/cc/COM1374/ec-com1374-en-es.htm

19. Filimonau V. and M. Högström (2017), The attitudes of UK tourists to the use of biofuels in civil aviation: an exploratory study, *Journal of Air Transport Management*, 63:84-94.

20. FIN (2019), Backgrounder: proposed application of the Federal Carbon Pollution Pricing System in Alberta, Ottawa. Retrieved from: https://www.canada.ca/en/department-finance/news/2019/06/backgrounder-proposed-application-of-the-federal-carbon-pollution-pricing-system-in-alberta.html

21. GARDN (2020, September 30), GARDN is starting its transition towards a new mandate. Retrieved from: https://gardn.org/gardn-is-starting-its-transition-towards-a-new-mandate/

22. GARDN (2012), Annual Report 2011-2012, Montreal. Retrieved from: https://gardn.org/publications/annual-reports/

23. Gazis E., Mawhood B., Slade R., de Jong S.A. and R. Hoefnagels (2016), Stakeholder analysis of the renewable jet fuels innovation system, Climate-KIC RENJET Future Renewable Jet Fuel Supply Chains Project.

24. Gegg, P., Budd L. and S. Ison (2015), Stakeholder views of the factors affecting the commercialization of aviation biofuels in Europe, *International Journal of Sustainable Transportation*, 9(8) :542-550.

25. Gegg P., Budd L. and S. Ison (2014), The market development of aviation biofuel: drivers and constraints, *Journal of Air Transport Management*, 39:34-40.

26. Government of British Columbia (2018), CleanBC Climate Action Plan, Victoria. Retrieved from: https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/cleanbc/cleanbc_2018-bc-climate-strategy.pdf

27. Government of Canada (2017), Canada's 2017 Nationally Determined Contribution submission to the United Nations Framework Convention on Climate Change, Ottawa. Retrieved from: https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Canada%20First/Canada%20First%20NDC-Revised%20submission%202017-05-11.pdf

28. Government of Canada (2016), Pan-Canadian Framework on Clean Growth and Climate Change, Ottawa. Retrieved from: http://publications.gc.ca/collections/collection_2017/eccc/En4-294-2016-eng.pdf

29. ICAO (2019), Destination green: the next chapter. Retrieved from: https://www.icao.int/environmental-protection/Documents/ICAO-ENV-Report2019-F1-WEB%20%281%29.pdf

30. ICAO (2014), Overview of alternative jet fuels in 2014, published in IATA, *Report on alternative fuels*. Retrieved from: https://www.icao.int/environmental-protection/GFAAF/Documents/Overview%20of%20Alternative%20Jet%20Fuels%20in%202014.pdf

31. NARA (2015), Aviation fuel supply chain stakeholder perceptions of sustainable alternative jet fuel, presented at the Northwest Advanced Renewables Alliance's Annual Meeting, Spokane, WA. [PowerPoint slides] Retrieved from: https://nararenewables.org/documents/2016/09/stakeholder-perceptions-of-jet-fuel.pdf/

32. NRTEE (2011), Paying the price: the economic impacts of climate change for Canada, Climate Prosperity Report 04, Ottawa. Retrieved from: http://nrt-trn.ca/wp-content/uploads/2011/09/paying-the-price.pdf

33. Rains T., Winter S.R., Rice S., Milner M.N. and Z. Bledsaw (2017), Biofuel and commercial aviation: will consumers pay more for it? *International Journal of Sustainable Aviation*, 3(3) :217-232.

34. Smith P.M., Gaffney M.J., Shi W., Hoard S., Ibarrola Armendariz I. and D.W. Mueller (2017), Drivers and barriers to the adoption and diffusion of sustainable jet fuel (SJF) in the U.S. Pacific Northwest, *Journal of Air Transport Management*, 58:113-124.

35. Soria Baledón M., Trudel M. and N. Kosoy (2021), Alternative jet fuels and climate geopolitics: what, why does it and who matters in the environmental policy-making process. *International Journal of Sustainable Transportation*.

36. Soria Baledón, Mónica (2018) Stakeholders mapping. Report prepared by GARDN for Natural Resources Canada's (NRCan) Impact Canada Initiative – Biojet Innovation Challenge "Innovating for a Green Aviation Fuel Future", Montreal. Retrieved from: https://safcommunity.org/page/stakeholders-map-resources

37. Soria Baledón, Mónica (2017), "Regulations for Oilseeds as Alternative Fuel Feedstocks", in BioFuelNet Canada, *What role of advanced biofuels in Canada? A Q&A of policy impacts and options*, pp.25-31. Retrieved from: http://www.biofuelnet.ca/nce/wp-content/uploads/2013/02/Biofuel-QA-Report-KTF-Apr-6-Final.pdf

38. Snoddon C., Mordvinova V., Doctoroff F., Di Piétro L. and L. McKeown (2020), COVID-19 impacts on civil aviation: an international comparison. Report prepared for Statistics Canada. Retrieved from: https://www150.statcan.gc.ca/n1/en/pub/45-28-0001/2020001/article/00084-eng.pdf?st=R7tS7etI

39. Timmis, Andrew (2015), A stakeholder approach to sustainable development in UK aviation, Sheffield University Management School. [Doctoral dissertation]

40. TC (2019), Canada's Action Plan to Reduce Greenhouse Gas Emissions from Aviation. 2018 Annual Report, Ottawa. Retrieved from: https://tc.canada.ca/sites/default/files/migrated/2019_2020_ah_03_report_e_accessible.pdf

41. TC (2018), Canada's Action Plan to Reduce Greenhouse Gas Emissions from Aviation. 2017 Annual Report, Ottawa. Retrieved from: https://tc.canada.ca/sites/default/files/migrated/2017annualreport_canadaactionplan_en.pdf

42. TC (2016), Canada's Action Plan to Reduce Greenhouse Gas Emissions from Aviation. 2015 Annual Report, Ottawa. Retrieved from: https://tc.canada.ca/sites/default/files/migrated/canadas_action_plan_reduce_greenhouse_gas_emmissions_aviation.pdf

43. TC (2012), Canada's Action Plan to Reduce Greenhouse Gas Emissions from Aviation, Ottawa. Retrieved from: https://tc.canada.ca/sites/default/files/migrated/aviationghgactionpan_eng.pdf

44. van Dyk S., Ebadian M., Su J., Larock F., Zhang Y., Monnier J., Wang H., Santosa D.M., Olarte M.V., Neuenschwander G., Rotness L.J., Elliott D.C., Drennan C., O'Connor D., Meijerinck O., Burns A., Reid C., García Claro M., Lakeman M. and J. Saddler (2019), Assessment of likely maturation pathways for production of biojet fuel from forest residues. Vancouver: University of British Columbia. Retrieved from: https://gardn.org/wp-content/uploads/2019/11/GARDN-NEC-21-ATM-project-final-report-public-release-1.pdf

Regulations, documents, resolutions, working papers and information papers

Government of Canada

45. Greenhouse Gas Pollution Pricing Act (GGPPA). S.C. 2018, c.12, s.186. Retrieved from: https://laws-lois.justice.gc.ca/PDF/G-11.55.pdf

46. Renewable Fuels Regulations (RFR). SOR/2010-189. Retrieved from: https://laws-lois.justice.gc.ca/PDF/SOR-2010-189.pdf

International Civil Aviation Organization (ICAO)

47. 37th Assembly Resolution A37–19: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Climate change, October 2010. Retrieved from: https://www.icao.int/environmental-protection/37thAssembly/A37_Res19_en.pdf

48. Present and future aircraft noise and emissions trends, A39-WP/55 [Presented by the Council of ICAO], 17/06/2016. Retrieved from: https://www.icao.int/Meetings/a39/Documents/WP/wp_055_en.pdf

ASTM International standards

49. ASTM D7566, 2020b (2009), Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons, West Conshohocken: ASTM International. Retrieved from: http://www.astm.org

Appendix

Template of GARDN survey

1. Background information

1.1. Your name and/or your organization

1.2. What are your main areas of activity/affiliation in the sector of SAF? (More than 1 answer is possible)

- ☐ Academia
- ☐ Advocacy
- ☐ Airline operator
- ☐ Airport
- ☐ Certification
- ☐ Consortium
- ☐ Consulting
- ☐ Feedstock production and processing
- ☐ Financing
- ☐ Fuel producer
- ☐ Fuel supplier
- ☐ OEM
- ☐ R&D
- ☐ Provincial government
- ☐ Federal government
- ☐ Other:

1.3. Where do most of your activities take place? (More than 1 answer is possible)

- ☐ Ontario
- ☐ Quebec
- ☐ Nova Scotia
- ☐ New Brunswick
- ☐ Manitoba
- ☐ British Columbia
- ☐ Prince Edward Island
- ☐ Saskatchewan
- ☐ Alberta
- ☐ Newfoundland and Labrador
- ☐ Territories (Northwest Territories, Yukon, Nunavut)
- ☐ Canada
- ☐ International
- ☐ Other:

1.4. In your opinion, what feedstocks would make the most sense to use for SAF production in your region? (More than 1 answer is possible)

- ☐ Algae
- ☐ Lignocellulosic biomass
- ☐ Municipal solid waste (MSW)
- ☐ Oils and fats
- ☐ Other carbon sources
- ☐ Sugar and starches
- ☐ Other:

2. Innovation / R&D / Technology development

2.1. What are the main R&D or innovation gaps in Canada?

2.2. In your main field of activity, what would be the most “low-hanging fruit” activities to help the technology development in this sector in Canada? (Short term)

2.3. Economics aside, what solutions could be imagined with the best social and environmental impacts for this industry? (Long term)

3. Production / Scale-up / Commercialization

3.1. Have you encountered specific risks in the SAF supply chain and what could be done to minimize or eliminate those risks?

3.2. What are the main technical issues and difficulties in scaling up the production of SAF?

3.3. What would you suggest to facilitate the certification process of SAF?

3.4. How would you evaluate the potential scope of impact of the following stakeholders?

	Low impact	Medium impact	High impact
International Organizations (ICAO, IATA, etc.)	○	○	○
Federal government	○	○	○
Provincial governments	○	○	○
Feedstock providers	○	○	○
Technology developers	○	○	○
End users	○	○	○
Citizens	○	○	○

3.5. Please comment on your answers to the previous question.

3.6. What are the main commercial barriers to scaling up SAF in Canada? What would be the most effective (or creative) solutions to overcome those barriers?

4. Financing and funding

4.1. What are the main barriers to accessing the capital? What would help minimize those barriers?

4.2. What are the main financial risks (real or perceived) related to financing SAF projects? What could be done to minimize those risks?

4.3. What role can airlines and airports play in supporting and financing SAF projects?

4.4. What is your understanding of the price difference between SAF and conventional jet fuel?

4.5. In the context of a carbon tax, what price would be required for 1 tonne CO_2 to close the gap and level prices between SAF and fossil jet fuel?

4.6. What would be the best way to close the price gap between conventional jet and SAF?

4.7. In your opinion, who should support the biggest share of the extra cost related to SAF? (1 answer only)

☐ Federal government with off-take agreements
☐ Private aviation (e.g. private jets, air shows, recreation)
☐ Travel for business
☐ Tourism / frequent flyers (the more you fly = the more you pay)
☐ Other:

4.8. What would be the most effective way for the public sector to invest in SAF-related projects? (More than 1 answer is possible)

☐ Investing in collaborative R&D projects
☐ Investing in production facilities and infrastructure
☐ Funding support for the certification process
☐ Financial incentives for private-sector purchase agreements
☐ Federal procurement
☐ Other:

5. How can the public sector help?

5.1. What policy changes (or new policies) do you think would be most effective in helping the development of a Canadian SAF supply chain?

5.2. What regulation changes (or new regulations) do you think would be most effective in helping the development of a Canadian SAF supply chain?

5.3. What other initiatives could the public sector put in place to help the SAF sector in Canada?

5.4. What kinds of collaborations between private and public sectors could be imagined to help develop SAF?

5.5 What kinds of collaborations between federal and provincial governments could be imagined to grow the SAF sector in Canada?

6. Other creative ideas...

6.1. What would be the best way to enhance collaboration and co-creation in this sector?

6.2. What other creative ideas and concrete solutions can you think of to help the Canadian SAF sector become the most successful and the most sustainable in the world?

Foreword to chapter 6

The sixth chapter focuses on identifying and mapping the universe of stakeholders across provincial jurisdictions with the purpose of supporting and accelerating the development of domestic supply chains of AJF in Canada. This chapter also presents an updated version of the research conducted between 2017-2019 for assisting Natural Resources Canada's (NRCan) in the design of The Sky's the Limit Challenge, and for gathering and engaging a community of interest to advance Canadian AJF production.

Chapters 6 was originally written by the author of this thesis while employed at GARDN. Full authorship of chapter 6 as presented in this doctoral research corresponds to Mónica Soria Baledón. There were no other contributing authors to this chapter nor to the institutional report published by GARDN in 2018 as Soria Baledón, Mónica (2018) Stakeholders mapping. Report prepared by GARDN for Natural Resources Canada's (NRCan) Impact Canada Initiative – Biojet Innovation Challenge "Innovating for a Green Aviation Fuel Future", Montreal. Available at: https://safcommunity.org/page/stakeholders-map-resources

6

Development of SAF supply chains in Canada: mapping the stakeholders

6.1. Paving the way forward

The use of sustainable aviation fuels (SAF) is one of the four mechanisms established by the United Nations International Civil Aviation Organization (ICAO) to achieve carbon-neutral growth from 2020 onwards[1]. This aspirational target was endorsed and included in Canada's Action Plan to Reduce Greenhouse Gas Emissions from Aviation, submitted by the Federal Government in 2012 in fulfillment to ICAO's 37th Assembly resolution A37-19.

Following the signing of the Paris Agreement in 2015, Canada also released its Mid-Century Long-Term Low-Greenhouse Gas Development Strategy during the 22nd session of the Conference of the Parties (COP22) to the United Nations Framework Convention on Climate Change (UNFCCC) in Marrakech, to renew its climate action goals and commit to reduce its national greenhouse gas emissions in 30 percent by 2030 compared to 2005 levels[2].

Canada's commitments are foundational to the Pan-Canadian Framework on Clean Growth and Climate Change (PCF) and the competitiveness of the Canadian aerospace industry is increasingly dependent on its ability to adopt environmentally sustainable practices that can also contribute to the targets of the United Nations Sustainable Development Goals[3] (SDGs). Whereas the use of sustainable aviation fuels could significantly advance the mitigation efforts of the Canadian air transport sector, there is presently no domestic production of SAF at the commercial scale.

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[1] As discussed throughout this thesis, SAF are certified alternative jet fuels (AJF) that can be continually and repeatedly resourced in a manner consistent with the preservation of the Earth's ecological balance, and consistent with social and economic aims (A39-3; CAAF/2-WP/03; ATAG 2017). In this particular chapter, SAF is used as an aspirational term for future Canadian production.

[2] Reductions from domestic aviation are governed by Canada's commitments under the Paris Agreement, while the international targets follow those set in 2009 by the International Air Transport Association (IATA), consisting of: (1) increasing the annual average fuel efficiency by 1.5%, (2) achieving carbon-neutral growth from 2020 and (3) halving the sector's emissions by 2050 compared to 2005 levels.

[3] See GARDN (2020), Sustainability in air travel. GARDN's contributions to the United Nations Sustainable Development Goals. Available at: https://gardn.org/wp-content/uploads/2020/07/SUSTAINABILITY-IN-AIR-TRAVEL-UN-SDGs-GARDN_compressed.pdf

In this context, this chapter compiles, updates and expands part of the research work conducted by the author while employed by the Green Aviation Research and Development Network (GARDN), that is publicly available through GARDN's SAF Community platform[4]. The objective of the report published in July 2018, was to assist Natural Resources Canada's (NRCan) *The Sky's the Limit Challenge* in identifying, classifying and mapping national and international[5] stakeholders for the development of Canadian-based SAF supply chains.

The Sky's the Limit Challenge was launched in August 2018[6] as part of NRCan's Impact Canada Initiative for stimulating innovation and accelerating the transition to a clean-growth economy. The Challenge consists of two competitions (view Figure A). The "Green Aviation Fuels Innovation Competition" aims at developing and scaling up innovative, sustainable and competitive SAF production processes, while the "Cross-Canada Flight Competition" consists of using Canadian-made SAF with a minimum blend of 10% in a commercial flight across the country[7].

In May 2019, four finalists to the first competition were announced and in March 2021, a CAD $5 million grand prize will be awarded to help commercialize the winning project. The second competition will close in January 2021, and a CAD $1 million prize will be awarded to the first SAF producer capable of supplying 2,500 litres of SAF that are compliant with the Canada General Standards Board (CAN/CGSB 3.23-2019) and ASTM International standards (ASTM D7566).

6.2. Methods

A stakeholder database was created[8] with information obtained from primary (i.e. attendance to conferences, workshops and events) and secondary sources (i.e. corporate websites, specialized

[4] Soria Baledón, Mónica (2018) Stakeholders mapping. Report prepared by GARDN for Natural Resources Canada's (NRCan) Impact Canada Initiative – Biojet Innovation Challenge "Innovating for a Green Aviation Fuel Future", Montreal. Available at: https://safcommunity.org/page/stakeholders-map-resources
[5] Only international stakeholders with operations and/or experience in Canada were included.
[6] Updates are communicated through NRCan's Challenge website at https://impact.canada.ca/en/challenges/green-aviation
[7] WestJet and Air Canada will serve as carriers to the competition.
[8] Accessible separately as an Excel file.

online magazines and news sites) during the months of April and May 2018. Stakeholders were identified and classified in twelve categories[9] according to their type of activity[10]. These include:

1. **Academia** – Group or individuals belonging to a community or environment concerned with the pursuit of research, education and scholarship, including but not limited to colleges, academies and universities.

2. **Advocacy** – Group or individuals that publicly support for a particular cause. Support can take place through the organization of events, workshops, HR training, trade missions, outreach, the promotion of partnerships and other collaboration schemes, the provision of certain business services (i.e. technical studies, market studies, etc.).

3. **Airline operator** – An aircraft operator that, for remuneration, provides scheduled or non-scheduled air transport services to the public for the carriage of passengers, freight or mail.

4. **Certification** – Also known as accredited registrar, an association accredited by a recognized accrediting body for its competence to audit and issue certification confirming that an organization meets the requirements of a standard.

5. **Consortium** – An association of organizations (public, private, social, academic, etc.) formed to undertake an enterprise beyond the human, material and financial resources of any one of its members. This category focuses on business-oriented consortia and excludes research oriented-consortia, which are classified as "R&D".

6. **Consulting** – Group or individuals that provide expert advice to individuals and/or organizations in a professional field.

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[9] Airports were not classified separately, but they were rather included within the advocacy category since national and regional airports in Canada are represented by the Air Transport Association of Canada (ATAC), the Canadian Airports Council (CAC) and the National Airlines Council of Canada (NACC).

[10] Some of these organizations may regularly undertake complementary activities that fall within more than one of the above categories.

7. **Feedstock production and processing** – Individual or group of organizations engaged in agricultural or forestry operations for the purpose of producing food, feed or raw materials. This category includes cooperatives.

8. **Financing** – Organizations that provide capital for business activities, making purchases or investing.

9. **Fuel producer** – Organizations that manufacture energy carriers (liquid, solid and/or gaseous) from biogenic (i.e. biomass) and non-biogenic (i.e. crude oil, natural gas, coal, bitumen, municipal solid waste or MSW, industrial gases, etc.) materials.

10. **Fuel supplier** – Intermediate organizations that link fuel producers and end users by transporting and delivering energy carriers.

11. **OEM** – OEM stands for Original Equipment Manufacturer. OEMs are organizations that manufacture and repair parts and equipment that are used as components by other manufacturing companies.

12. **R&D** – R&D stands for Research and Development and includes organizations that conduct activities toward the innovation, development and/or improvement of products, services and procedures. This category includes research-oriented consortia.

The identified stakeholders were further filtered by applying the following three criteria:

1. Expertise within the aerospace/air transport sector,
2. Expertise on cleantech, renewable energies and on alternative fuels to fossil carriers,
3. Expertise on alternative jet fuels (AJF) and/or sustainable aviation fuels (SAF)[11].

[11] Not all alternative jet fuels (AJF) can be considered sustainable aviation fuels (SAF) unless the feedstock production and the fuel production are certified as such by a recognized accrediting body (e.g. ISO, RSB, RSPO, etc.). For the purpose of this chapter and of the original report published in 2018, both types of alternative fuels (AJF/SAF) were considered so as to be as inclusive as possible of the potential stakeholders with the technological capabilities to produce these fuels.

Supplemental filters include:

a. Corporate nationality (Canadian or international),
b. The scope of their activity (national, provincial and regional),
c. Their geolocation.

For the category of fuel producers, stakeholders were analyzed based on:

a. Type of feedstock used (sugars and starches, oils and fats, municipal solid waste, lignocellulosic biomass, algae, co-processing with crude oil, and other carbon sources).
b. Type of energy carriers produced (ethanol, biodiesel, hydrogenated fuels and others),
c. Nominal capacity and operativity.

6.3. Understanding the universe of stakeholders

A total of 144 national and international stakeholders were identified based on the aforementioned criteria and classified according to their type of activity. Figure 6.1 shows the type and number of stakeholders relevant to the SAF value chain, 10 of which are international and 134 are Canadian.

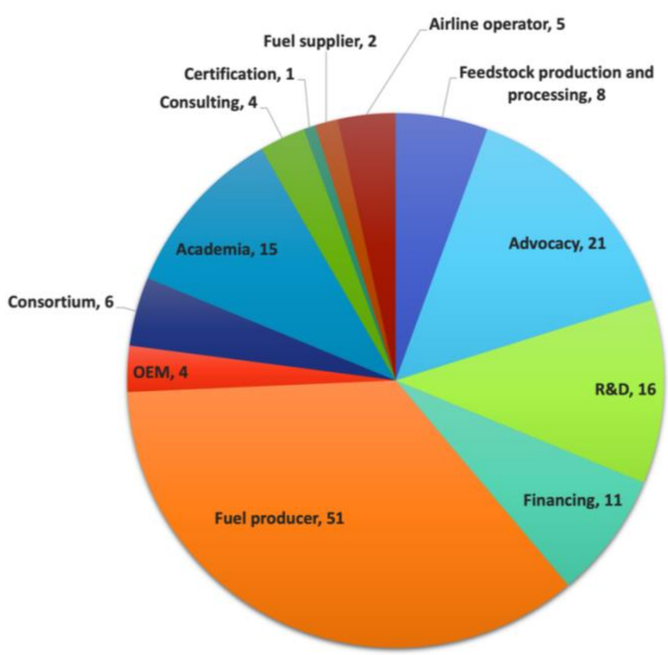

Figure 6.1. Stakeholders per type of activity

For airline operators, only the largest Canadian airlines were included in the database for a couple of reasons. First, most of the large commercial operators (i.e. Air Canada, WestJet and Porter Airlines) have participated in a Canadian AJF/SAF- related project and/or initiative led by GARDN or an equivalent organization (e.g. BiofuelNet Canada). Second, all the international offtake agreements signed until May 2018 between AJF/SAF fuel producers and commercial airlines involve large operators, suggesting the latter are in better financial capacity than local and regional airlines to invest in alternative fuels.

However, certain regional airports and airlines in Canada could benefit from local SAF production if their cost can provide an advantage compared to the cost of delivering conventional jet fuel to those locations. According to Transport Canada, there are over 100 regional and local airlines that hold Air Operator Certificates that serve communities all across the country, and 26 airports belonging to the National Airport System (NAS) that serve 94% of all scheduled passenger and cargo traffic in Canada[12].

The category "feedstock production and processing" is mainly comprised by agricultural and forestry associations, rather than by individual producers, since they are the main point of contact with local and regional stakeholders that are otherwise untraceable over the Internet. Furthermore, these associations recognize and continuously advocate for the adoption of best practices, particularly those that could bring economic value into their constituencies, therefore representing an opportunity to The Sky's the Limit Challenge in terms of outreach.

The sole exceptions in this category that were accounted for on an individual base are Agrisoma Biosciences and Canfor Pulp, because they are both active participants in alternative fuels projects (SAF and biocrude, respectively) and initiatives worldwide.

[12] The remaining 6% is served by over 700 regional and local airports with an annual traffic below 200,000 passengers (TC, accessed on October 20th 2020).

The category "fuel producers" (Fig.6.3-6.6) includes ethanol and biodiesel stakeholders as well as those capable of producing hydrogenated fuels[13], biocrude or other alternative fuels. This allowed to incorporate a larger sample of stakeholders with access to feedstocks (oils, fats, sugars and starches) suitable for conversion to AJF/SAF, regardless of the fuel markets they are currently supplying.

Whereas some of the stakeholders included in the database do not have experience with AJF/SAF, most of them have some expertise in areas related to the aerospace industry, the air transport sector, clean technologies and other alternative fuels to fossil carriers (i.e. biodiesel, ethanol, renewable diesel and methanol), whose cross-sectoral strengths could be harnessed so as to integrate regional supply chains for SAF.

6.3.1. Consortia, collaborative initiatives and joint ventures

The development and establishment of a Canadian SAF industry requires the integration of supply chains that involve leveraging the material, financial and human resources of a variety of stakeholders. For example, a handful of technological breakthroughs in Canada have taken place in the form of joint ventures (Licella Pulp Joint Venture, VANERCO) and collaborative initiatives (COSIA's Algae Project) that were specifically created to introduce novel biomass conversion processes for the production of a variety of bio-based products.

Particularly, the logistics for the development a Canadian SAF industry demand great effort and coordination amongst a large and highly diversified number of organizations to undertake an enterprise beyond their individual resources. An association of this kind is known as a consortium and the stakeholders identified under this category are mainly business-oriented and not research oriented[14]. The identified business-oriented consortia are:

[13] Hydrogenated fuels comprise a variety of oils-and-fats-based fuels such as renewable gasoline, renewable diesel, alternative jet fuels, and others, that are produced by chemically reacting molecular hydrogen with an element or a compound in the presence of a catalyst.
[14] These were classified as "R&D".

1. Aéro Montréal
2. Bioénergie La Tuque (BELT)
3. Biomass North Development Centre (BiomassNorth)
4. Canadian Biomass Innovation Network (CBIN)
5. Clean Resource Innovation Network (CRIN)
6. Commercial Aviation Alternative Fuels Initiative (CAAFI) [15]

All of these consortia have innovation and research components to their activities for advancing the transition to a low-carbon economy in Canada from a multi-and-cross-sectoral approach. Between 2009 and 2019, five project-specific consortia of this kind were created through GARDN programs in order to establish the foundations for the development of Canadian-based supply chains for alternative aviation fuels[16].

6.3.2. Supply chains: where are stakeholders located?

Figure B shows the distribution of the 144 identified stakeholders per type and location. The stakeholders classified as "Canada" include public, private and non-for-profit organizations with operations in several Canadian provinces, for example: WestJet (AB), Viking Air (BC), Bombardier (QC), the National Research Council (ON), the Air Transport Association of Canada (ON), etcetera.

Fuel producers that conduct operations in more than one province were individually accounted for in each of those provinces. For example, Husky Energy operates ethanol plants in SK and MB, while Methes operates biodiesel plants in ON and QC. This was done to facilitate the identification of potential cluster formation and project development in regions where most stakeholders within a SAF supply chain are located.

[15] CAAFI is based in the US but it is actively engaged in AJF projects and initiatives in Canada.
[16] Chapter 5 provides a detailed description of these projects.

An interactive map (Fig.6.2) was also created to geolocate stakeholders and provide users with a visualization tool of their distribution across Canada. The map has been regularly updated since July 2018 and it is accessible to the public for free through GARDN's SAF Community platform[17].

Figure 6.2. Map of stakeholders

At the moment, the open-access software has limited capabilities to incorporate additional information layers (i.e. oil & gas infrastructure, agricultural and forestry growing regions, etc.), which are nonetheless publicly available through the departmental websites of the Government of Canada for further reference.

For example, Quebec and Ontario were identified as the provinces with the greatest number and diversity of stakeholders within the value chain of SAF compared to the rest of Canada, where some of the fuel producers are located within a ~50km ratio to the nearest airport.

Conversely, Alberta has a much larger number of fuel producers compared to other type of in-province stakeholders, where Edmonton stands out as a region with great potential for cluster

[17] https://safcommunity.org/page/stakeholders-map-resources

formation along with Toronto and Sarnia, which are all well connected by rail[18], road[19] and by pipelines[20].

The interactive map includes a layer of fuel producers classified per type of feedstock rather than per end product, as it can be used as an indicator of the local availability of feedstocks for alternative uses other than food (Fig.6.3).

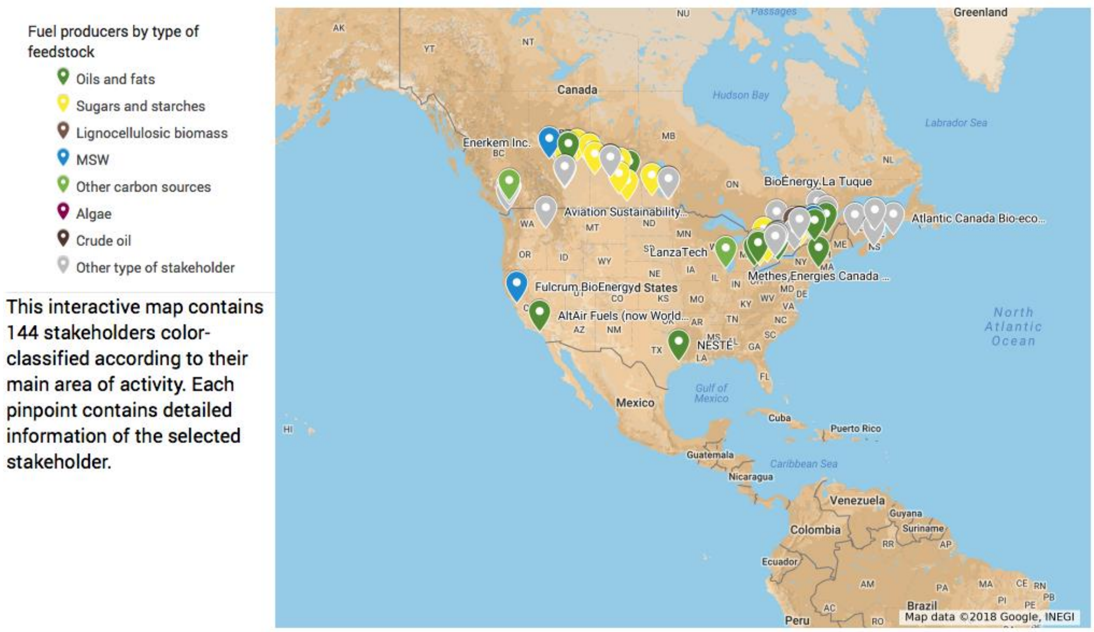

Figure 6.3. Geolocation of fuel producers per type of feedstock

6.3.3. Domestic production capacity: overview of alternative fuels producers

At present, only a few companies produce biocrude (Ensyn, Licella and Steeper Energy), methanol (Enerkem) and gaseous fuels (Atlantec and Enerkem), and most of the Canadian production of alternative fuels is devoted to ethanol and biodiesel so as to fulfill the provincial and federal

[18] Canada's railway network can be consulted through the Railway Association of Canada's Rail Atlas, accessible at: https://rac.jmaponline.net/canadianrailatlas/

[19] Maps for the Trans-Canada Highway (TCH) are accessible from Transport Canada's website (https://www.tc.gc.ca/eng/policy/acg-acgd-menu-highways-map-2152.htm). Maps of the National Highway System (NHS) are managed by each provincial/territorial jurisdiction.

[20] Canada's network of pipelines can be consulted through the National Energy Board's Interactive Pipeline Map, accessible at: https://www.neb-one.gc.ca/sftnvrnmnt/sft/dshbrd/mp/index-eng.html

blending mandates[21]. However, 11 of these companies (view Table A) have the technology to produce renewable diesel[22] and/or AJF/SAF from a variety of feedstocks if regulatory and policy incentives are put in place. The majority of these companies have experience or have exposure to AJF/SAF production, which makes them suitable candidates for participating in The Sky's the Limit Challenge.

According to Figure 6.4, most fuel producers, including those listed in Table A, are located in Ontario and Alberta. Stakeholders classified under "hydrogenated fuels" include producers of renewable diesel, renewable gasoline, alternative jet fuel, naphtha, etc., while those classified as "others" include biocrude, methanol and other gaseous fuels.

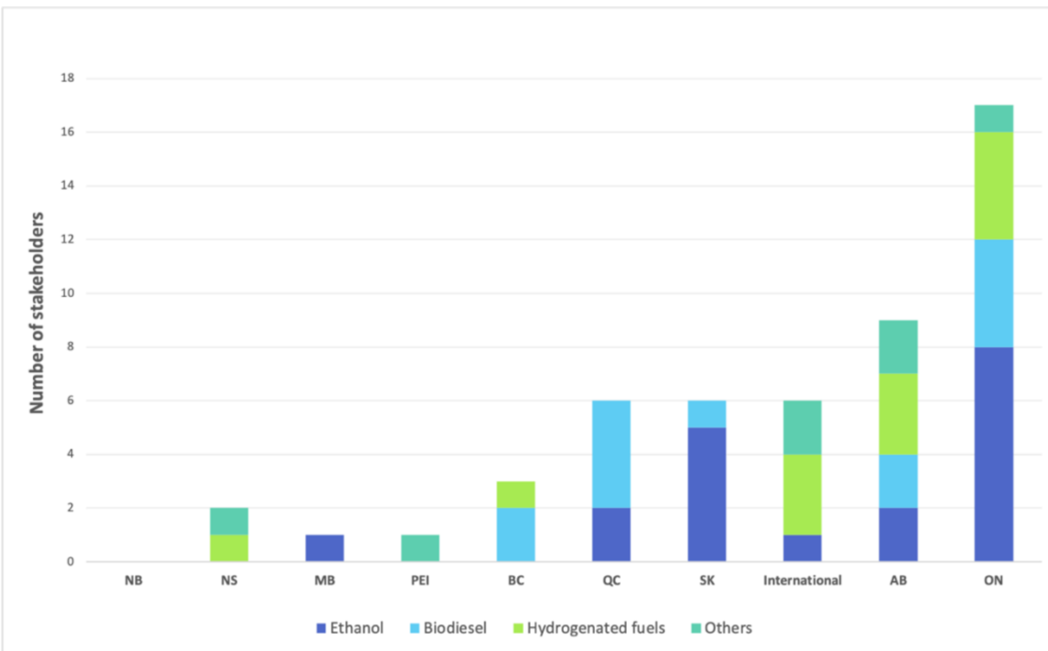

Figure 6.4. Fuel producers per type and location

[21] At the federal level, the Renewable Fuel Regulations require fuel producers and importers a minimum blend of 5% of ethanol per volume of gasoline produced or imported, and a minimum blend of 2% of renewable content per volume of diesel and heating distillate oil produced or imported. At the provincial level, British Columbia, Alberta Saskatchewan, Manitoba and Ontario have blending mandates for gasoline and diesel ranging between 5 to 8.5% for ethanol and 2-4% of renewable content in diesel. A detailed analysis of the federal and provincial renewable fuel regulations can be found in Soria Baledón, Mónica (2017), "Regulations for Oilseeds as Alternative Fuel Feedstocks", in BioFuelNet Canada, What role of advanced biofuels in Canada? A Q&A of policy impacts and options, pp.25-31. Available at: http://www.biofuelnet.ca/nce/wp-content/uploads/2013/02/Biofuel-QA-Report-KTF-Apr-6-Final.pdf

[22] Renewable diesel blended with a wider-cut HEFA-SPK yields a high-freeze point jet fuel known as HEFA+, which is currently pending certification approval under ASTM 7566.

Figure 6.5 shows a similar distribution as Figure 6.4, but the stakeholders were classified per type of feedstock rather than per type of fuel. This is relevant insofar it provides additional information on the local availability of certain types of feedstocks for alternative uses other than for feed and food. For example, oils and fats[23] are still the preferred type of feedstock for the production of alternative fuels, followed by sugars and starches[24].

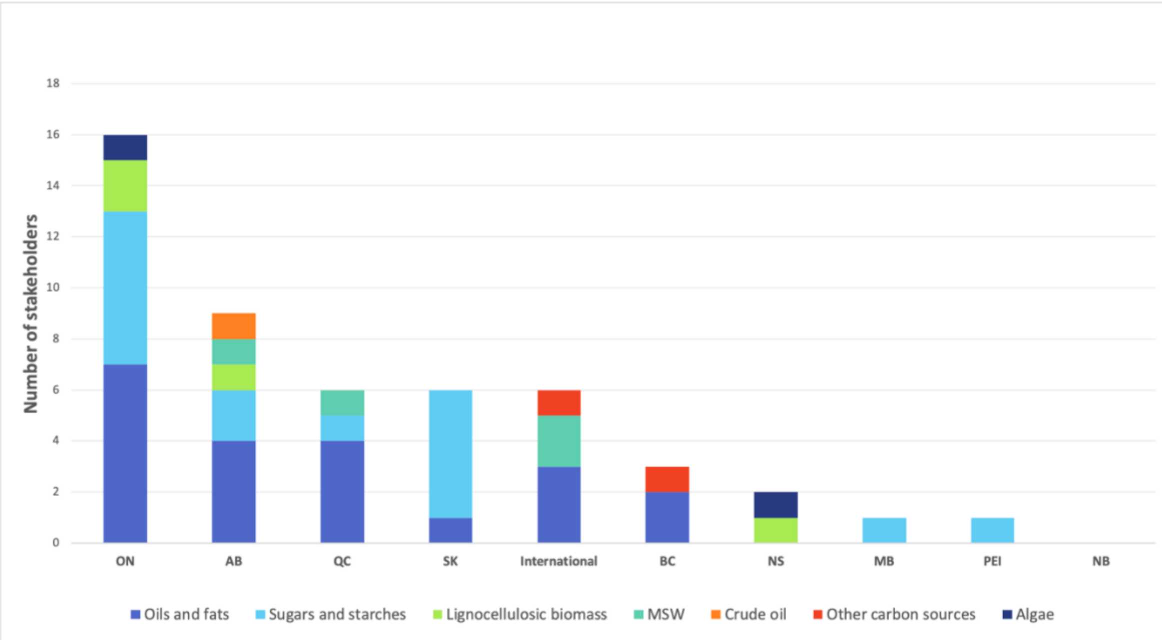

Figure 6.5. Fuel producers per type of feedstock and location

A handful of Canadian-based companies have started to produce alternative fuels from lignocellulosic sources (Woodland, Cellufuel, Ensyn and Steeper Energy), from algae (Pond Technologies) and from municipal solid waste or MSW (Enerkem and VANERCO); but none of them currently produce hydrogenated fuels. At present, only LanzaTech and Advanced Chemical Technologies have the technology to commercially produce fuels and chemicals from recycling a variety of industrial waste carbon streams; however, the latter specializes in methanol production and has currently no projects or initiatives to incur in AJF/SAF production.

[23] Canola, animal fats and recycled oils remain the primary feedstocks for biodiesel production. Other suitable oilseed crops include soybean, flaxseed and to a lesser extent, Ethiopian mustard (*brassica carinata*) and largeseed false flax (*camelina sativa*).

[24] Mainly from wheat and corn.

A one-of-a-kind potential producer is BC-based Carbon Engineering Ltd., a company that specializes in carbon capture by turning CO_2 into calcium carbonate ($CaCO_3$) pellets, which are used as precursors for syngas production. Syngas can then be converted into liquid hydrocarbons, including AJF/SAF via thermo-catalysis[25].

Figure 6.6 shows the most common types of fuels produced from a variety of feedstocks. As discussed in the beginning of this section, Canada has a handful of companies capable of producing hydrogenated fuels from oils and fats that are currently converted into biodiesel. Almost all processed sugar and starches from corn and wheat are used for ethanol production, except for Atlantec Bioenergy Corporation, a PEI-based company that also produces biogas for electricity generation as a secondary energy-product to ethanol.

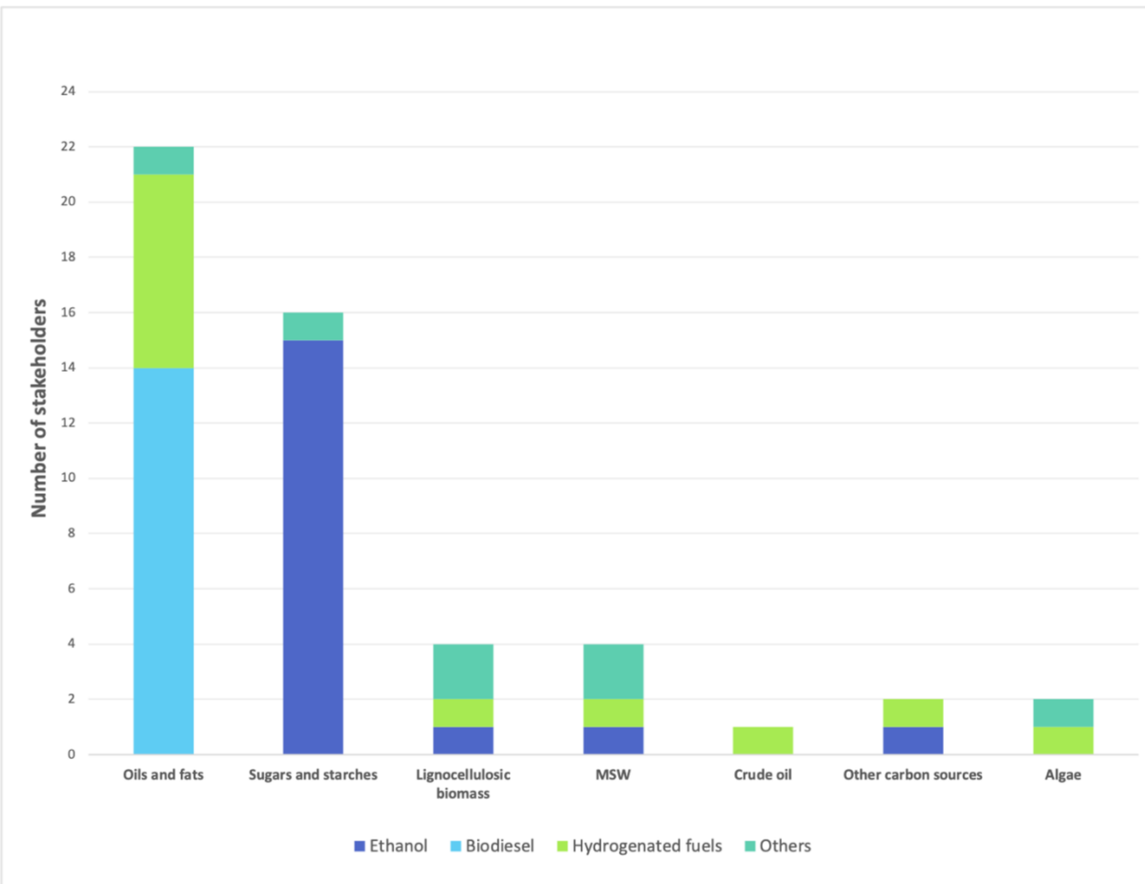

Figure 6.6. Producers per type of fuel and feedstock

[25] This conversion pathway is not ASTM-certified.

Producers that rely on lignocellulosic biomass mainly produce ethanol (Woodland Biofuels, and VANERCO) and biocrude for heating and/or co-processing in oil refineries (Steeper Energy, Licella and Ensyn). Cellufuel (dark green in "lignocellulosic biomass" bar in Figure 6.6) does not appear to be operative; otherwise it would be the only Canadian company capable of producing hydrogenated fuels from forestry biomass.

Enerkem and VANERCO are the only companies in Canada to use MSW as feedstock for ethanol, methanol and syngas production. Pond Technologies and MARA are the only companies that can produce hydrogenated fuels and biocrude from algae, but none of them have commercial-scale plants in operation.

The category "crude oil" was included for reference purposes to Canadian Natural (classified as oil and gas), a member of Canada's Oil Sands Innovation Alliance (COSIA), and partner to the Algal Carbon Conversion Project (Algae Project) with NRC and Pond Technologies, a pilot-scale biorefinery that mixes CO_2 emissions from oil and gas operations with algae to produce AJF, HDRD, biodiesel, nutraceuticals, animal feed and fertilizer.

6.4. BioPortYVR: the role of policies and regulations

In May 2019, four finalists to the "Green Aviation Fuels Innovation Competition" were awarded CAD $2 million each to support their projects (NRCan 2019). Three out of these companies (Enerkem, SAF+ Consortium and FORGE Hydrocarbons) are located in Alberta, Quebec and Ontario, which were identified in this study as the provinces with the greatest potential for the development of SAF supply chains.

The fourth finalist, Carbon Engineering, is located in British Columbia, where the provincial government announced its CleanBC Climate Action Plan[26] in December 2018; four months after the launching of The Sky's the Limit Challenge. The plan encompasses a comprehensive low-

[26] https://blog.gov.bc.ca/app/uploads/sites/436/2019/02/CleanBC_Highlights_Report_Updated_Mar2019.pdf

carbon fuel policy review[27] to reduce the price differential between petroleum-based jet fuels (CAF/LCAF) and sustainable aviation fuels (SAF) by generating credit revenue from the production of alternative fuels.

The proposed incentives have the potential to create enough demand for SAF in British Columbia for equally supporting ASTM-certified and emerging conversion pathways to become commercially viable. In was in this context – and drawing on the experience of jurisdictions with comprehensive clean fuel policies (e.g. California, Sweden, the Netherlands and other select European states), that GARDN launched BioPortYVR[28] in November 2019 to implement an integrated SAF supply chain in British Columbia.

BioPortYVR is a collaborative industry-led project conformed by GARDN, SkyNRG, Waterfall Group and the Vancouver Airport Authority (YVR). The project evaluated the feasibility of developing regional supply chains to distribute SAF to airlines at the Vancouver International Airport and surrounding airports, where SAF production and uptake could lead to CO_2 emissions reductions up to 90% on a lifecycle basis compared to petroleum-based fuels, improve local air quality around airports and stimulate economic development (BioPortYVR, 2020).

The feasibility study included a techno-economic analysis (TEA) of SAF production pathways that primarily rely either on oils and fats or on forestry residues. According to the TEA, the most plausible short-term feedstock and technology combination is dependent on oils and fats, where the potential credit revenue generated through the BC-LCFS could significantly close the premium gap between CAF and SAF (BioPortYVR, 2020).

Whereas the scope of the BioPortYVR's feasibility study was limited to ASTM-certified conversion processes, the development of SAF supply chains in British Columbia that rely on other feedstock/technology combinations (e.g. Carbon Engineering), could greatly benefit from the inclusion of SAF in the provincial low-carbon fuel policies and regulations, the upcoming new

[27] British Columbia's low-carbon fuel standard (BC-LCFS) sets annual targets to reduce the carbon intensity (CI) of fuels used in the province. The BC-LCFS comprises the Greenhouse Gas Reduction Act and the Renewable & Low Carbon Fuel Requirements Regulation.
[28] https://bioportyvr.ca

fuel delivery system for YVR, and the commitment of the air transport sector to attain its climate action goals.

6.5. Concluding remarks

The use of sustainable aviation fuels is expected to help the Canadian commercial aviation sector to meet its domestic and international carbon reduction targets, however, the challenge is significant as there is currently no production capacity to supply future demand for fuel.

According to the information gathered for this report, Canada could start producing nearly 300 million litres of SAF per year (~3% of domestic CAF demand in 2018) if incentives at the federal and the provincial levels are set in place. The publication of the CleanBC Climate Action Plan and the launching of the BioPortYVR clearly illustrate this point, as several provinces other than British Columbia have greater potential for the development of regional SAF supply chains based on the profile, type, expertise and geolocation of stakeholders identified in this study.

Initiatives such as The Sky's the Limit Challenge are fundamental to support innovative research and development in Canada through the facilitation of consortia-building and fuel readiness level acceleration, but they will not, if standalone, lead to the creation of a domestic SAF market.

Canada has greater chances to successfully meet its climate goals the sooner the federal and provincial renewable fuels regulations shift from a volumetric, to a more comprehensive approach to transport fuels that sets targets to reduce their carbon intensity and progressively taxes carbon in petroleum-based ones.

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Declaration of interest

None.

Literature cited

1. ATAG (2017, November), Beginner's guide to sustainable aviation fuel (3rd edition). Retrieved from: https://www.atag.org/component/attachments/attachments.html?id=604

2. BioPortYVR (2020), Toward a Made-in-BC Clean Fuel Supply Chain: Discussion paper. Retrieved from: https://bioportyvr.ca/paper/

3. Derkach K., Soria Baledón M., Avalle E. and M. Kacem (2019), Sustainable aviation fuels: a Canadian Perspective. Report prepared by GARDN for Environment and Climate Change Canada (ECCC), Montreal. Retrieved from: https://safcommunity.org/page/white-paper

4. ECCC (2016), Canada's Mid-Century Long-Term Low-Greenhouse Gas Development Strategy, Gatineau. Retrieved from: https://unfccc.int/files/focus/long-term_strategies/application/pdf/canadas_mid-century_long-term_strategy.pdf

5. GARDN (2020), Sustainability in air travel. GARDN's contributions to the United Nations Sustainable Development Goals. Retrieved from: https://gardn.org/wp-content/uploads/2020/07/SUSTAINABILITY-IN-AIR-TRAVEL-UN-SDGs-GARDN_compressed.pdf

6. Government of British Columbia (2018), CleanBC Climate Action Plan, Victoria. Retrieved from: https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/cleanbc/cleanbc_2018-bc-climate-strategy.pdf

7. NRCan (2019, May 29), "Canada announces four finalists for The Sky's the Limit Challenge $5-million grand prize". Retrieved from: https://www.newswire.ca/news-releases/canada-announces-four-finalists-for-the-sky-s-the-limit-challenge-5-million-grand-prize-845183710.html

8. Soria Baledón, M. (2018) Stakeholders mapping. Report prepared by GARDN for Natural Resources Canada's (NRCan) Impact Canada Initiative – Biojet Innovation Challenge "Innovating for a Green Aviation Fuel Future", Montreal. Retrieved from: https://safcommunity.org/page/stakeholders-map-resources

9. Soria Baledón, M. (2017), "Regulations for Oilseeds as Alternative Fuel Feedstocks", in BioFuelNet Canada, *What role of advanced biofuels in Canada? A Q&A of policy impacts and options*, pp.25-31. Retrieved from: http://www.biofuelnet.ca/nce/wp-content/uploads/2013/02/Biofuel-QA-Report-KTF-Apr-6-Final.pdf

10. TC (2020, October), List of airports owned by Transport Canada. Retrieved from: https://tc.canada.ca/en/aviation/operating-airports-aerodromes/list-airports-owned-transport-canada

11. TC (2012), Canada's Action Plan to Reduce Greenhouse Gas Emissions from Aviation, Ottawa. Retrieved from: https://tc.canada.ca/sites/default/files/migrated/aviationghgactionpan_eng.pdf

Regulations, documents, resolutions, working papers and information papers

International Civil Aviation Organization (ICAO)

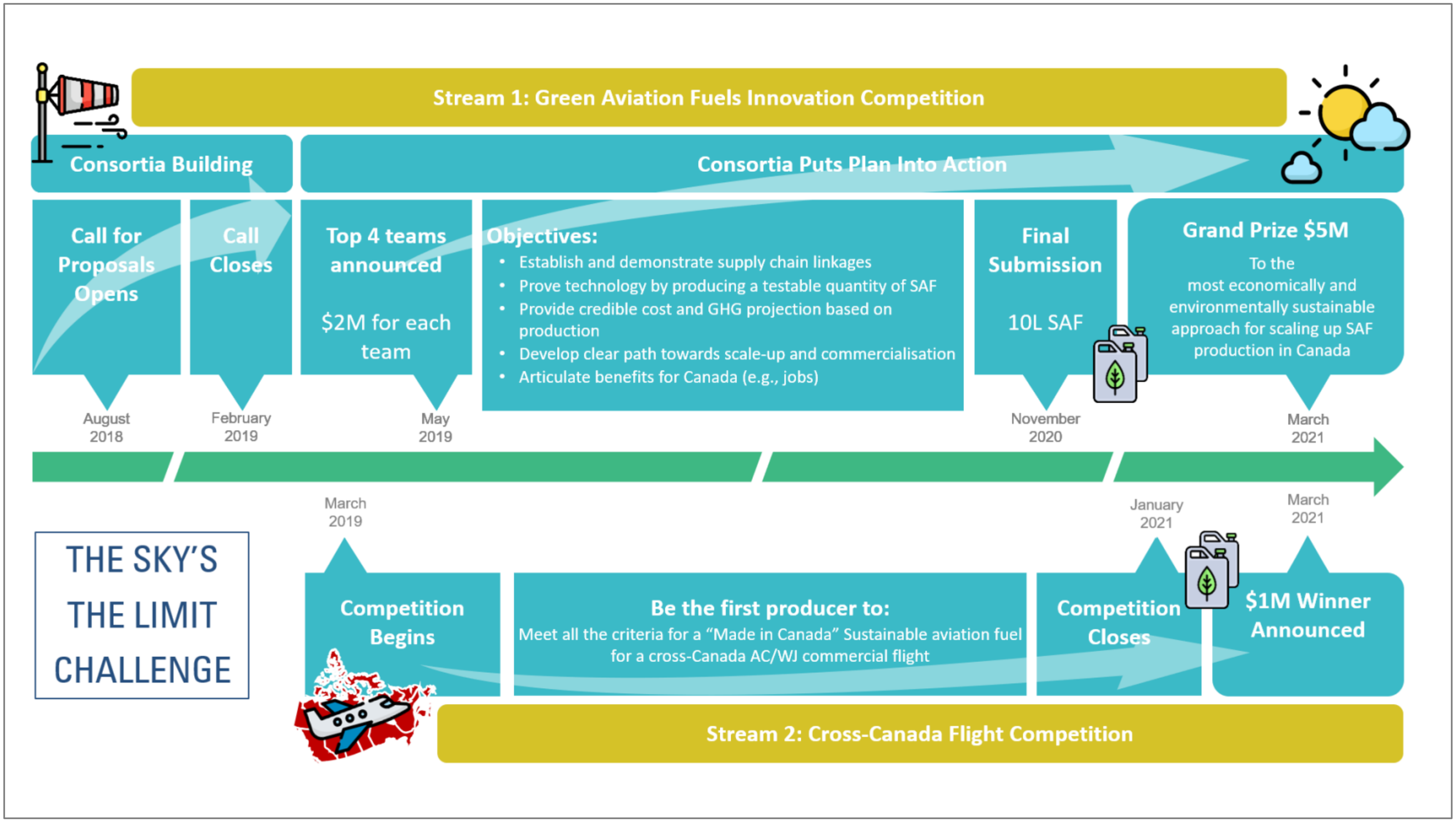
12. 39th Assembly Resolution A39–3: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Global Market-based Measure (MBM) scheme, October 2016. Retrieved from: https://www.icao.int/environmental-protection/Documents/Resolution_A39_3.pdf

13. 37th Assembly Resolution A37–19: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Climate change, October 2010. Retrieved from: https://www.icao.int/environmental-protection/37thAssembly/A37_Res19_en.pdf

14. Definitions. CAAF/2-WP/03. 24/07/17. Retrieved from: https://www.icao.int/Meetings/CAAF2/Documents/CAAF.2.WP.003.1.en.pdf

Appendices

Figure A. Overview of The Sky's the Limit Challenge



Derkach K., Soria Baledón M., Avalle E. and M. Kacem (2019), Sustainable aviation fuels: a Canadian Perspective. Report prepared by GARDN for Environment and Climate Change Canada (ECCC), Montreal. Retrieved from: https://safcommunity.org/page/white-paper

Figure B. Stakeholders per type and location

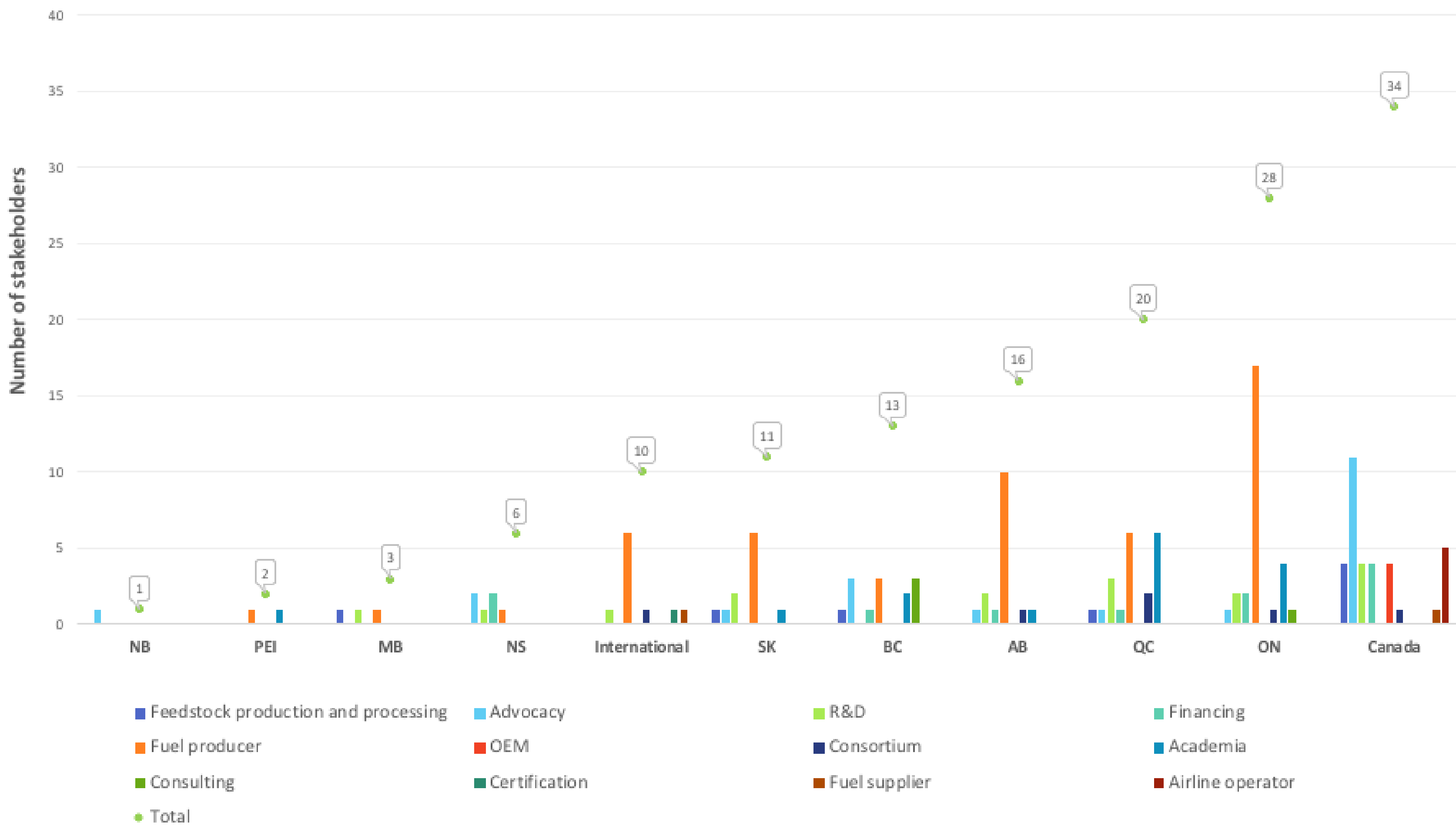


Table A. Potential fuel producers with capabilities for renewable diesel and AJF/SAF production in Canada

No.	Name*	Prov.	Expertise	Experience with AFJ	Feedstock	Product(s)	Capacity
1	Biox Corporation (Hamilton)	ON	Biodiesel, refined glycerin and bioheavies (non-ASTM grade methyl esters).	Not in Hamilton, but Biox's acquisition by World Energy opens opportunities for technology transfer from AltAir.	Oils and fats	HDRD and biodiesel	67MLY nominal capacity
2	Biox Corporation (Sombra)	ON	Biodiesel.	This plant is being retrofitted to produce renewable diesel.	Oils and fats	HDRD and biodiesel	50MLY nominal capacity
3	Canadian Natural Resources Limited	AB	Natural gas, light and heavy crude oil, bitument and syntheci crude oil (SCO).	Canadian Natural is part of Canada's Oil Sands Innovation Alliance (COSIA) and has been closely involved in the Algal Carbon Conversion Project (Algae Project) with NRC and Pond Technologies.	Crude oil	Oil-based products	Unknown but operational for traditional oil and gas refining
4	Cellufuel	NS	Renewable diesel.	Unknown	Lignocellulosic biomass	Renewable diesel	Not operational
5	FORGE Hydrocarbons	ON	Renewable diesel, solvents and chemicals.	Their proprietary lipid-to-hydrocarbon (LTH) technology is optimized for renewable diesel but it can produce AJF. Its first commercial plant is under construction in Sombra, ON, with a projected capacity of 28MLY.	Oils and fats	Renewable diesel and AJF	Under construction
6	Enerkem	AB	Methanol and cellulosic ethanol.	They are capable of producing AJF from methanol using the ATJ conversion pathway.	MSW and forestry biomass	Methanol, ethanol and AJF	Not yet operational
7	NextStep Renewable Energy Inc.	AB	Renewable diesel.	In 2018, NSRE and Edmonton International Airport (EIA) announced the signing of an MOU to produce AJF to be supplied at the airport. This also made NSRE a member of the Alberta Aerospace and Technology Centre (AATC) which focuses on attracting and building a cluster of activity in aerospace in the province.	Oils and fats	HDRD and AJF	Not operational

No.	Name*	Prov.	Expertise	Experience with AFJ	Feedstock	Product(s)	Capacity
8	Pond Technologies Inc.	ON	Algal-based commercial products.	Participant in COSIA's Algae Project to produce AJF, HDRJ and biodiesel.	Algae	HDRD, AJF and biodiesel	Pilot-scale plant
9	SBI Bioenergy	AB	Drop-in fuels. Shell currently holds exclusive licensing rights on SBI's technology.	Currently under ASTM 4054 certification process in partnership with Shell (PICFTR).	Oils and fats	HDRD, AJF, biodiesel and gasoline	Proposed 240MLY plant in Edmonton
10	Bioénergie La Tuque (BELT)	QC	Alternative fuels and power.	Unknown. However, NESTE is a member to the consortium and BELT has expressed interest to explore the potential of AJF production.	Lignocellulosic biomass	HDRD, AJF, methane, propane, gasoline, hydrogen and electricity.	Not operational
11	Carbon Engineering Ltd.	BC	Carbon capture and syngas.	CE can synthesize liquid hydrocarbons from syngas; however, their conversion process is not ASTM-certified and their proprietary technology remains at the pilot scale.	Other carbon sources (syngas from CO_2 capture + H_2 from water electrolysis).	Renewable diesel, gasoline and AJF.	Pilot plan scale (no information on size but prospective 111MLY plant).

* MARA Renewables Corporation was not included in the table since its main activity is research and development, however it received $9.6 million CAD from the Government of Canada through Sustainable Development Technology Canada (SDTC) to fund an AJF project from algae (status unknown).

7

Piecing all together: greater climate ambition for a new geopolitical reality

(General discussion of results)

This chapter compiles and jointly discusses the findings presented throughout this thesis, in response to the research questions formulated in chapter 1 and reproduced below.

1. How have emissions from the air transport sector been discursively constructed and articulated as a global issue?
2. What are the premises and effects of the problem representations underlying ICAO's – and more broadly the industry's – alternative jet fuel strategies?
3. How can the dominant premises and problem representations be disrupted so as to constructively and inclusively inform policies on AJF within and beyond national jurisdictions?

These questions underpinned the general objectives of this doctoral dissertation, which individually make up each of the sections in this chapter. As most of the research took place ahead of the COVID-19 outbreak, section 7.5 expands on the initial reflections within this thesis apropos the impacts of the pandemic in AJF deployment and the future of aviation.

7.1. Beyond the 2.4% global CO_2 contribution

The discursive foundations of aviation climate policy were investigated in chapters 2,3 and 4. The analyses revealed instances of data obliquity, information gaps and asymmetries underlying unquestioned forms of problem representations – whether under scientific knowledge, collective narratives and organizational practices – concerning the environmental impacts of aviation.

At the microscale, these (mis)representations have bolstered a "psychology of denial" in end-users, particularly for leisure travel; yet, at the macroscale, they have encompassed – and will continue to effect – significant risks and repercussions. Overall, problem representations have historically upheld a positive image of aviation as socially desirable and economically all-important by overemphasizing its benefits, belittling the impacts, and enshrining technological and market-based solutions to address them.

Foremost, they have: a) precluded a comprehensive understanding of the environmental and climate effects of aviation beyond its ~2.4% global CO_2 contribution to global warming; b) ensued a generalized understating of the urgency to implement more ambitious mitigation and adaptation strategies to address them; and c) begotten substantial discursive, subjectification and lived repercussions on people and the environment.

The examination of the historical process, the circumstances, the relations and the individual narratives on which dominant representations (as defined in chapter 4 based on stakeholders' salience) rest upon, unveiled the extensiveness of the weak sustainability approach to aviation's growth embedded in policies and regulations worldwide.

As discussed in chapter 3, these representations have left unquestioned the notion of progress that has associated for centuries, the ideas of human advancement and wellbeing to those of economic and material growth. This notion of progress has been foundational to the neoliberal concept of sustainable development, whereby the expansion of air transport has trumped the need for environmental protection.

In the context of the Paris Agreement, the climate commitments undertaken by the aviation industry in 2009, together with those agreed upon by the ICAO the following year, have not appropriately accounted for the required carbon reductions to limit global warming well below 2°C. This observation is not new but is relevant insofar emissions from international aviation remain discursively separated and addressed from those of domestic aviation, despite being implicitly included in the overarching goals of this landmark agreement.

Thereupon, chapters 2 to 4 examined several options to address information gaps and asymmetries precluding a better understanding of the environmental effects of aviation beyond its ~2.4% global CO_2 contribution.

These consist of:

a. Enhanced transparency and access to data collected by governments, industry, academia and other third-parties on air transport emissions from and beyond fuel combustion,
b. The harmonization of epistemologies for measuring, allocating, assessing, verifying and reporting environmental data so as to render it comparable,
c. A reassessment of the sectoral approach to the Sustainable Development Goals (SDGs) for aligning aviation policies and actions with the aims of the UN 2030 Agenda for Sustainable Development,
d. Greater engagement of stakeholders in the qualitative production, appraisal and use of knowledge, and
e. A broad outreach to end-users for getting them involved, individually, in climate action.

7.2. Status, challenges and opportunities for AJF

Alternative jet fuels were approved for use in commercial aviation in 2009, and production capacity is forecast to reach 2.7 Mt (3.5 bn litres) per year by 2025, amounting to 7 $MtCO_2$ avoided[1]. Based on the latest industry estimates, approximately 490Mt/y^{-1} AJF (~620 bn litres) from various feedstock sources could supply between 84% to 109% of the projected global jet fuel demand of 450-570Mt (~570-720 bn litres) by 2050; potentially achieving 1.2$GtCO_2$ annual reductions.

Advances in power-to-liquid (PtL) and solar-thermochemical AJF conversion pathways could make it possible for AJF to theoretically supply future demand for jet fuel in its entirety, since the broad adoption of alternative propulsion architectures based on renewable sources of hydrogen and electricity is unlikely before 2040. Although these conversion pathways would address some of the techno-economic caveats and sustainability concerns of AJF dependent on land-based bioenergy feedstocks, PtL and solar-thermochemical AJF are not readily available to apportion significant volumes in years to come.

[1] Assuming an 80% CO_2 lifecycle abatement potential.

Looking out to 2050, the use of additives to allow for higher AJF blends with CAF, together with the progressive removal of ASTM D7566 melding limits, are expected to yield additional emissions reductions, as AJF have been performance tested at 100% and newer engines are expected to operate using neat AJF by 2030. The removal of blending limits would also result in considerable costs savings by eliminating the need for dedicated infrastructure at existing storage and tank terminals.

Meanwhile, the sustainable production of AJF is essential for supporting the energy transition of the aviation sector, which could be forestalled by the current design and operationalization framework for eligible fuels – notably by the inclusion of LCAF – under the ICAO's CORSIA. Whilst the air transport industry has pledged to robust sustainability standards for global deployment of AJF, adherence solely to CORSIA's criteria encompasses extensive short and long-term social, environmental and economic risks.

These encompass: a) higher carbon debts, ecosystem damage and welfare loss from unsustainable AJF production, b) distortion of long-term market signal for AJF with high sustainability profiles, c) constraints on investment and innovation for next-generation clean-fuel technologies, d) increased sectoral reputational risk and, foremost, e) a continued dependence on fossil-derived jet fuels internationally.

7.3. The role and influence of stakeholder perceptions in decision-making

Socio-environmental research has progressively acknowledged stakeholder viewpoints as paramount to inform and improve environmental governance, where the understanding of *what* matters, *why* does it and *who* says so in decision-making processes concerning AJF, is as relevant to their commercialization as economies of scale.

Chapter 4 unveiled four metanarratives, three out of which have a distinctive weak sustainability approach to international aviation's growth and one that is typically representative of strong sustainability. These findings are consistent with those from previous chapters, as several of the individual narratives analyzed using mixed methods are reflective of the problem representations that are cemented on the neoliberal definition of sustainable development.

Nonetheless, all metanarratives have a common ground of beliefs and understandings to bring valuable expertise from low-salient and non-stakeholders – most of which are strong sustainability advocates – into the formulation of policies on AJF beyond the work of the ICAO; who will retain the responsibility of effectively engaging its constituency into meaningful climate action.

Internationally, advances in conversion technologies, flight and fuel distribution demonstrators, and the simplification of fuel certification processes over the past 15 years, have taken place through a variety of collaborative arrangements, mainly in the form of multi-stakeholder partnerships. Yet, building global capacity for AJF production remains contingent on policies and regulations within national jurisdictions to stimulate market development over the next years.

Therefore, understanding the development of AJF as energy vectors of mounting geopolitical and economic relevance, demands the acknowledgement of stakeholders' role in decision-making processes that favor transparency, accountability, fairness and inclusiveness.

7.4. Lessons from Canada

As detailed in chapters 1 and 5, Canada was selected as case study for a number of reasons, ranging from its aviation emissions' profile to the abundance and variety of biogenic feedstocks for upscaling AJF in several of its provinces. Foremost, chapters 5 and 6 were developed in parallel to policy discussions to include AJF in federal and provincial climate regulations.

Canada has significant experience in collaborative research and development on the supply chain components for domestic AJF production, but until recently, it lacked an identifiable community of stakeholders across its landmass for engaging into regional commercialization efforts. For this reason, the findings from chapter 6 were foundational to the launching in 2018 of The Sky's the Limit Challenge – whose timelines were adjusted in response to the COVID-19 pandemic –, and beyond that, for gathering and actively participate stakeholders in the qualitative production, assessment and use of knowledge that brought forth SAFI Canada.

On the latter, the data collected from GARDN's expanded community of interest on AJF, was crucial for identifying the gaps and obstacles for the development of supply chains and consequently, to define the guiding principles, strategic areas, themes and objectives of an AJF national roadmap rooted in strong sustainability values.

Aligned with this aspiration, SAFI Canada was purposefully designed to unsettle through strategic actions, some of the discursive and non-discursive practices of the Canadian aviation sector that still mirror those identified at the international level. Some of these actions include phasing out CAF subsidies, promoting intermodal passenger transport and reducing non-essential travel[2].

As of April 2021, the inclusion of AJF as opt-in for credit generation under the federal Clean Fuel Standard (CFS) and the British Columbia Low-Carbon Fuel Standard (BC-LCFS), is still under discussion. Yet, Canada faces a unique juncture for accelerating the commercial deployment of AJF by leveraging on:

1. The accomplishments and experience gained from the GARDN projects and the community of interest created thereof,
2. The international efforts on RD&D, financing and supply chain development since 2008,
3. Its abundance of biogenic feedstock sources from its agricultural and forestry sectors for long-term production of AJF,
4. The entry into force in all Canadian provinces (backstop jurisdictions and provinces with existing carbon-pricing systems) of a carbon levy on CAF since April 2019,
5. The entry into force of the liquid stream of the CFS in 2022,
6. The active engagement of stakeholders along the supply chain of AJF in Canada and abroad,

[2] GARDN officially concluded its mandate in March 2021 (GARDN 2021), but the legal and administrative process to constitute SAFI Canada as the entity responsible for the development of AJF supply chains is ongoing.

7. The technological and business innovations brought about by federal and provincial programs and initiatives, and
8. The implementation of multi-stakeholder projects such as the CBSCI and BioPortYVR.

7.5. The *business of freedom* in a post-pandemic future

The COVID-19 outbreak led to a near shutdown of the air transport sector worldwide that resulted in a net financial loss of approximately USD 118.5 billion by the end of 2020. Albeit air traffic forecasts out to 2050 are conservative, a global rebound to pre-pandemic levels is expected by 2024, encompassing an annual sectoral growth of 4.1% with an associated 2.9% annual increase in emissions.

By 2050, emissions from international and domestic aviation are anticipated to reach 1.82 $GtCO_2$, a figure that does not consider the radiative forcing effect of non-CO_2 emissions at cruise altitude. In this scenario, the development of AJF is still likely to be driven by environmental concerns and less by the perennial fear of peak oil, where a weak sustainability approach to aviation's growth could progressively engender radical stakeholder activism – such as the European *flygskam* movement – with effecting geopolitical ramifications.

As argued in chapter 4, even when the pandemic makes difficult to assess the potential long-term repercussions of this social movement on global demand, the growing anti-aviation sentiment prompted the air transport industry and national governments to seek greater climate ambition.

Notably in Europe, the aviation community has committed to become carbon-neutral by 2050 (EU Aviation Round Table 2020) in support of the targets of the EU Green Deal and those of the Paris Agreement. The broad adoption of AJF is at the core of the European roadmap to achieve this goal (NLR and SEO 2021) and the aviation industry has pledged to robust sustainability standards to upscale regional production.

But in other parts of the world, the redirected focus on the economic recovery and the restoration of air travel services, particularly in countries strongly dependent on trade and tourism, will precede climate action in the foreseeable future.

The sightseeing *flights to nowhere*, the onboard dining experiences at the tarmac, the catering service and the merchandise sales (Asaf 2020; Robson 2020; Wei 2020), illustrate some of the strategies adopted by air carriers globally – even those in good financial standing at the time of writing, for coping with the drastic drop in air traffic demand and the ever-changing travel restrictions to contain the pandemic.

Whilst these alternative services can somewhat protect cash reserves and provide a temporary relief for airlines, airports and some of their subcontractors, flying *to nowhere* contravenes the industry's environmental commitments adopted over a decade prior. But most concerning is the selling out of these services, particularly in Asia and Australia, where several national air carriers had demonstrated leadership in the promotion of AJF through multi-million dollar forward-purchase agreements and capital investments in commercialization projects[3].

Whereas a deeper understanding of the behavioral and psychological motivations for air travel is essential to effectively engage end-users into climate action at the individual level, it goes beyond the scope and objectives of this thesis. Nonetheless, this *pandemic phenomenon* emerges in full congruence with the findings of chapters 1 through 4 apropos the micro and macroscale ramifications of the problem misrepresentations upheld by the aviation sector.

Unless the discursive foundations of current air transport policies – nationally and supranationally – are questioned and disrupted, the aviation sector risks falling behind the unprecedented range and scale at which the world's energy systems are transforming away from fossil resources. Foremost, they risk aggravating the environmental and climate impacts of air travel – understood in terms of Jevons' paradox[4] and the rebound effect – as global demand recovers post-pandemic.

[3] https://aviationbenefits.org/environmental-efficiency/climate-action/sustainable-aviation-fuel/the-leading-edge/ on April 4, 2021.

[4] In *The Coal Question* (1865), W.S. Jevons observed that technological efficiency gains increased rather than decreased the overall consumption of coal, iron and other resources during the Industrial Revolution (Alcott 2005).

The latter observation is not minor, as Jevon's paradox obliges to reflexively and truthfully attempt reconciling the challenges posed by aviation's growth – in the context of a global energy transition so heavily dependent on scarce and finite resources – with current developmental pathways entrenched in neoliberal notions of progress, prosperity and happiness.

Whether by default or by design, air transport policies and regulations continue to approach and address sectoral emissions in silos. Yet, upscaling global AJF production will stay contingent on the removal of wider structural barriers for market creation and development.

At the national level, the Canadian case study offered a comprehensive overview of the status, challenges, opportunities and next steps for strategically addressing these barriers by means of a national roadmap, and a dedicated entity – SAFI Canada – responsible for its implementation.

At the international level, overcoming structural barriers for AJF deployment will strongly depend on the evolution of the ICAO's CORSIA throughout its lifetime. All things equal, in its current form it is probable to reinforce the sector's dependence on fossil-derived jet fuels in detriment of AJF with high sustainability profiles.

Nearly 25 years have passed since the adoption of the Kyoto Protocol[5], and though the recent entry into force of the Doha Amendment (UNFCCC 2020) signals willingness and political commitment by the international community to deliver on their climate pledges, the COVID-19 outbreak has exacerbated a variety of socio-environmental issues once inconspicuous.

The qualities that make most of the latter to be categorized as post-normal issues, also makes achieving the Paris Agreement's goals all more important. Thereupon, unsettling and replacing the intangible – but nevertheless real – discursive and non-discursive practices on which aviation policies and regulations are still cemented, will be crucial to overcome the structural barriers for

This rebound effect has been observed economy-wide, where degrowing resource consumption is improbable unless capped (Alcott 2015).
[5] Canada has been the only country to withdraw from the Kyoto Protocol, made effective on December 15, 2012. However, it remains bound by the mitigation and reporting requirements under the UNFCCC (UNFCCC 2014).

sustainable AJF deployment in a post-pandemic future where the *business of freedom*[6] has no intent to evanesce nor to recede.

And this endeavor is formidable.

[6] Presently used as the air transport industry's slogan, it vaguely alludes to the freedoms of the air, a set of commercial aviation rights for the movement of people and goods that entitles a country's airlines to enter and land in another country's airspace.

8

Moving forward and upward

(Conclusions)

This doctoral dissertation investigated the role for alternative jet fuels in mitigating the climate impacts of aviation out to 2050 and beyond.

This socio-environmental research was overarched by a Post-Normal Science (PNS) theoretical framework, where a mixed methodological approach to aeronautics and the application of out-of-field methods, were instrumental to the development of both the descriptive and the normative components of PNS.

The descriptive component of PNS centered on the implications for environmental governance, of defining post-normal issues in terms of what is and what can be known. Chapters 2, 3 and 4 analyzed the discursive and non-discursive practices, referred throughout this thesis as problem representations, apropos the environmental impacts of air transport.

Chapter 2 examined the foundations of environmental policy in the aviation sector; chapter 3 investigated the premises and effects underlying the ICAO's AJF strategy for addressing emissions from international aviation; and chapter 4 analyzed stakeholder narratives on AJF (*what* matters, *why* does it and *who* says so) as inputs for policy-making.

The normative component of PNS focused on identifying mechanisms for informing and improving decision-making in the air transport sector, based on reflexive, inclusive and transparent scientific inquiry. Chapters 4, 5 and 6 explored stakeholder participation in the context of international environmental governance and also within a national jurisdiction by using Canada as case study.

Chapter 4 bridged the descriptive and the normative components of PNS by ascertaining options for engaging stakeholders in the qualitative production, appraisal and use of knowledge on AJF within the scope of work of the ICAO. Chapters 5 and 6 operationalized the normative component of PNS by gathering a community of interest around AJF and using stakeholders' input and expertise in the definition of a national roadmap for Canada.

Chapter 7 compiled and jointly discussed the findings presented throughout this thesis and their contribution to each of this research's objectives.

Thereupon, it can be concluded that:

i. Problem misrepresentations of the environmental impacts of aviation have encompassed – and will continue to effect unless defied – micro and macroscale risks and repercussions on people and the environment.

ii. In the context of CORSIA, they may also hinder global deployment of sustainable AJF – as per the notion of strong sustainability – in years to come by: 1) encouraging the production of fossil-derived fuels (LCAF) and when more economical, 2) favoring carbon offsetting over direct emissions abatement.

    With some exemptions, notably of Scandinavian and select European countries, national jurisdictions are unlikely to seek greater climate ambition to address their emissions from domestic aviation, beyond what has already been agreed upon at the ICAO for international aviation.

iii. The active and inclusive participation of stakeholders in decision-making is paramount for qualitative environmental governance. Whereas a weak sustainability approach to aviation's growth is equally abiding in policies, regulations and most of the stakeholder narratives analyzed, cross-sectoral and multi-level stakeholder collaboration promises to bring strong sustainability perspectives into the formulation of policies on AJF.

iv. Whilst the Canadian air transport mirrors the weak sustainability approach observed in discursive and non-discursive practices internationally, Canada faces a unique juncture to regain leadership in the development and commercialization of AJF by leveraging on its abundant biogenic feedstock resources, its technological innovation capabilities, its extensive experience with multi-stakeholder partnerships on AJF projects and possibly, a propitious regulatory framework for including these fuels in federal and provincial legislations. Even so, Canada also has an enormous potential for LCAF production that may set it in the path of a continued dependence on fossil-based fuels.

v. The COVID-19 outbreak abruptly redirected the focus from climate action to the economic recovery and the restoration of air travel services in most parts of the world. In post-pandemic times, this could entail a magnified rebound effect on global emissions from aviation in the absence of more appropriate, realistic, fair and ambitious environmental commitments, suited to a new geopolitical reality shaped by the profound transformation of the world's energy systems.

8.1. Turning limitations into opportunities

The methodological proposal presented in this thesis was novel to the field of aeronautics, where some of its methods had only been applied in socio-environmental research since the 1990s. These include Funtowicz and Ravetz's Post Normal Science (PNS), Bacchi's What's the Problem Represented to be (WPR), and Stephenson's Q-method.

The ontological and epistemological flexibility of these methods was advantageous for approaching and reframing intractable and highly sensitive and/or politicized aspects of AJF; however, their existing body of research is highly heterogeneous in terms of conceptualizations, tools, best practices and applications.

The limited capabilities of freeware and proprietary software available in 2016 for creating and administering Q-sorts online, are a noteworthy limitation that resulted in days of laborious manual data entries and processing. But over the course of the COVID-19 pandemic, the emergence of online sorting tools and the enhancement of existing ones, anticipate a more standardized and efficient application of Q-method for collecting and processing data.

In general, access to information and to stakeholders were ofttimes difficult. As described in several chapters, the pervasiveness of data misrepresentations, information gaps and asymmetries within the aviation sector is abiding. Furthermore, information is routinely protected by confidentiality agreements whether or not it contains politically sensitive and/or proprietary data.

Whereas these limitations were attenuated while employed at the Green Aviation Research and Development Network (GARDN), this research encountered other sources of limitations. For example, the methodological design of the institutional report[1] on the status on AJF in Canada from which chapter 5 originated, was subject to internal approvals at GARDN. These approvals were independent to McGill University and they were contingent on the type and availability of resources (financial and in-kind), ongoing collaborative agreements with third-parties, quarterly targets and time constraints.

The demise of the BioFuelNet Canada as a member of the Networks of Centres of Excellence of Canada (NCE) at a very early stage of this research, threatened its viability due to the lack of funding and the scission of the teams created to fulfill the network's mandates.

Despite the symbolic contributions from the Department of Natural Resource Sciences (NRS) and the Student Aid Office at McGill University to keep this study afloat, the original vision – and ambition – of the author's doctoral proposal demanded adjustments to ensure its feasibility; some of which have now turned into opportunities for future research.

8.2. Future avenues for research

Most of the white and grey literature published in the last 20 years has focused on the chemistry of alternative jet fuels – still commonly referred to as biofuels, on the techno-economic analysis of conversion processes, on the characterization of biogenic feedstocks suitable for upscaling production, and more recently, on the environmental sustainability of alternative fuels and their policy and regulatory frameworks worldwide.

[1] Derkach K., Soria Baledón M., Avalle E. and M. Kacem (2019), Sustainable aviation fuels: a Canadian Perspective. Report prepared by GARDN for Environment and Climate Change Canada (ECCC), Montreal.

The academic literature on the social aspects of AJF is comparably scant despite their critical role for global deployment and, more broadly, for the formulation of transparent, inclusive and ambitious policies and regulations to comprehensively address the environmental impacts of aviation.

Fertile avenues for socio-environmental studies based on the findings – and the shortcomings – of this doctoral research abound. To begin with, studies that tackle the prevailing data misrepresentations, gaps and asymmetries in the aviation sector and consequently the narratives emerging thereof, would benefit scholarly discussions as much as policy-making, by portraying a more accurate picture of the scale, extent and type of challenges posed by aviation's growth in the context of a global energy transition that heavily depends on scarce and finite resources.

To illustrate this, the travel restrictions imposed by governments worldwide to contain the pandemic effected a surge in the demand for private jet travel that as of February 2021, was already operating at 90% of its sectoral capacity (Colombo 2021). Although this air transport segment is deemed to account for approximately 2% of the global CO_2 emissions from commercial aviation[2] (GAMA and IBAC 2016), this figure is probable to apportion a larger amount in the near future based on industry forecasts.

Beyond the work of the ICAO, there is great opportunity for applying mixed methods that have strong participatory components, to inform the AJF policies of large domestic aviation emitters such as the US, China, India and Brazil (Graver et al. 2020). For example, Giuseppe Munda's (2008) Social Multi-Criteria Evaluation (SMCE) is a tool that combines public and social choice tradition with multi-criteria decision theory and analysis, to examine complex policy issues – understood in terms of PNS – from an integrated perspective.

Aside from the air transport industry reports on its global contributions to the Sustainable Development Goals (SDGs), there are no scholarly assessments other than what has been discussed in this thesis and recently observed elsewhere (Gössling et al. 2019), despite the pertinence and relevance of the subject. Likewise, there are presently no academic studies that examine the

[2] This figure does not consider the radiative forcing of non-CO_2 emissions at cruise altitude.

behavioural aspects – beside imposing carbon levies on frequent flying – for engaging aviation users in AJF financing, particularly for leisure travel.

As these and other avenues for future socio-environmental and transdisciplinary research on AJF emerge, acknowledging these fuels as energy vectors of heightening geopolitical and economic relevance in post-normal times, is paramount for reconciling the ever pressing and urgent challenges of climate change and local pollution with those of economic growth and mobility.

References

(chapters 1, 7 & 8)

1. Alcott, B. (2015), Jevon's paradox (rebound effect), in D'Alisa G., Demaria F. and G. Kallis (eds.), *Degrowth: a vocabulary for a new era*, London/New York: Routledge.

2. Alcott, B. (2005), Jevon's paradox, *Ecological Economics*, 54:9-21.

3. ATAG (2021, April 4), The leading edge. Retrieved from: https://aviationbenefits.org/environmental-efficiency/climate-action/sustainable-aviation-fuel/the-leading-edge/

4. ATAG (2021, March 25), Sustainable aviation fuel. Retrieved from: https://aviationbenefits.org/environmental-efficiency/climate-action/sustainable-aviation-fuel

5. ATAG (2020a), Blueprint for a green recovery. Retrieved from: https://aviationbenefits.org/media/167158/bgr20_final.pdf

6. ATAG (2020b), Waypoint 2050 (1st edition). Retrieved from: https://aviationbenefits.org/media/167187/w2050_full.pdf

7. ATAG (2020c), Aviation: Benefits beyond borders. Retrieved from: https://aviationbenefits.org/media/167186/abbb2020_full.pdf

8. ATAG (2020d), Aviation's energy transition. Retrieved from: https://aviationbenefits.org/downloads/fact-sheet-5-aviations-energy-transition/

9. ATAG (2018), Aviation: Benefits beyond borders. Retrieved from: https://aviationbenefits.org/media/166344/abbb18_full-report_web.pdf

10. Asaf, S. (2020, September 22), "Qantas flight to nowhere sells out in 10 minutes", *Business Traveller*. Retrieved from: https://www.businesstraveller.com/business-travel/2020/09/22/qantas-flight-to-nowhere-sells-out-in-10-minutes/

11. Ayres R.U., van den Bergh J.C.J.M. and J. M. Gowdy (2001), Strong versus weak sustainability: economics, natural sciences and "consilience", *Environmental Ethics*, 23(2):155-168.

12. Bacchi C.L. (2009), *Analysing policy: What's the problem represented to be?*, Frenchs Forest: Pearson.

13. Bauen A., Bitossi N., German L., Harris A. and K. Leow (2020), Sustainable aviation fuels: status, challenges and prospects of drop-in liquid fuels, hydrogen and electrification in aviation, *Johnson Matthey Technology Review*, 64(3):263-278.

14. Brasseur G.P., Cox R.A., Hauglustaine D., Isaksen I., Lelieveld J., Lister D.H., Sausen R., Schumann U., Wahner A. and P. Wiesen (1998), European assessment of the atmospheric effects of aircraft emissions, *Atmospheric Environment*, 32:2329-2418.

15. Bosch J., de Jong S.A., Hoefnagels R. and R. Slade (2017), Aviation biofuels : strategically important, technically achievable, tough to deliver, Grantham Institute, Imperial College London. Retrieved from : https://www.imperial.ac.uk/media/imperial-college/grantham-institute/public/publications/briefing-papers/BP-23-Aviation-Biofuels.pdf

16. Boyd, R. (2019), Climate change mitigation, in ICAO (2019), Destination green: the next chapter, pp.174-176. Retrieved from: https://www.icao.int/environmental-protection/Documents/ICAO-ENV-Report2019-F1-WEB%20%281%29.pdf

17. BP (2020), Statistical Review of World Energy 2020 (69th edition). Retrieved from: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf

18. CBSCI (2019), HEFA Production and Feedstock. Retrieved from: https://cbsci.ca/reports/

19. Colombo, H. (2021, February 24), “The private jet industry is surging during Covid-19”. Columbus Business First. Retrieved from: https://www.bizjournals.com/columbus/news/2021/02/24/private-jets-thriving-during-pandemic.html

20. de Jong, S.A. (2018), *Green horizons : On the production costs, climate impact and future supply of renewable jet fuels*, Utrecht : Copernicus Institute of Sustainable Development.

21. Deane J.P. and S. Pye (2018), Europe’s ambition for biofuels in aviation. A strategic review of challenges and opportunities, *Energy Strategy Reviews*, 20:1-5.

22. Derkach K., Soria Baledón M., Avalle E. and M. Kacem (2019), Sustainable aviation fuels: a Canadian Perspective. Report prepared by GARDN for Environment and Climate Change Canada (ECCC), Montreal. Retrieved from: https://safcommunity.org/page/white-paper

23. DOE (2017), Alternative aviation fuels : overview of challenges, opportunities and next steps. Retrieved from: https://www.energy.gov/sites/prod/files/2017/03/f34/alternative_aviation_fuels_report.pdf

24. ECCC (2020), Pan-Canadian Framework on Clean Growth and Climate Change. Third annual synthesis report on the status of implementation, Gatineau. Retrieved from: http://publications.gc.ca/collections/collection_2020/eccc/En1-77-2019-eng.pdf

25. Elwood, S. (2009), Mixed methods: thinking, doing and asking in multiple ways, in Delyser D., Herbert S., Aitken S., Crang M. and L. McDowell (eds.), *The Sage handbook of qualitative geography*, London: Sage, pp.94-114.

26. Fichert F., Forsyth P. and H.M. Niemeier (eds.) (2020), *Aviation and climate change: economic perspectives on greenhouse gas reduction policies*, London/New York: Routledge.

27. Foucault, M. (1988), The concern for truth, in L.D. Kritzman (ed.), *Michel Foucault: politics, philosophy, culture. Interviews and other writings 1977-1984*, New York: Roultledge, pp.255-267.

28. Funtowicz S.O. and J.R. Ravetz (1993), Science for the post-normal age, *Futures*, 25(7):739-755.

29. GAMA and IBAC (2016), Business aviation commitment on climate change. Retrieved from: https://gama.aero/wp-content/uploads/GAMA-IBAC-Joint-Position-on-Business-Aviation-Tackling-Climate-Change-1.pdf

30. GARDN (2021, March 23), "GARDN will be ceasing its operations as of March 31, 2021". Retrieved from: https://gardn.org/gardn-will-be-ceasing-its-operations-as-of-march-31-2021/

31. Goodland, R. (1995), The concept of environmental sustainability, *Annual Review of Ecology and Systematics*, 26:1-24.

32. Gowdy, J.M. (2000), Terms and concepts in ecological economics, *Wildlife Society Bulletin*, 28(1):26-33.

33. Graver B., Rutherford D. and S. Zheng (2020), CO_2 emissions from commercial aviation: 2013, 2018, and 2019, ICCT. Retrieved from: https://theicct.org/sites/default/files/publications/CO2-commercial-aviation-oct2020.pdf

34. Grewe V. (2020), Aviation emissions and climate impacts, in Fichert F., Forsyth P. and H.M. Niemeier (eds.), *Aviation and climate change: economic perspectives on greenhouse gas reduction policies*, London/New York: Routledge, pp.4-15.

35. Gössling S. and A. Humpe (2020), The global scale, distribution and growth of aviation: implications for climate change, *Global Environmental Change*, 65:1-12.

36. Gössling S., Hanna P., Higham J., Cohen S. And D. Hopkins (2019), Can we fly less? Evaluating the 'necessity' of air travel, *Journal of Air Transport Management*, 81:101722.

37. Hileman J.I., Ortiz D.S., Bartis J.T., Wong H.M., Donohoo P.E., Weiss M.A. and I.A. Waitz (2009), Near-term feasibility of alternative jet fuels, RAND Corporation, TR-554-FAA. Retrieved from: https://www.rand.org/pubs/technical_reports/TR554.html

38. IATA (2020a), Sustainable aviation fuel (SAF) fact sheet. Retrieved from: https://www.iata.org/contentassets/8dc7f9f4c38247ae8f007998295a37d5/saf_general-fact-sheet_advocacy_june2020.pdf

39. IATA (2020b, November 24), “Deep losses continue into 2021”, Press release no.95. Retrieved from: https://www.iata.org/en/pressroom/pr/2020-11-24-01/

40. IATA (2015), Sustainable aviation fuel roadmap. Retrieved from: https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/safr-1-2015.pdf

41. IATA (2013), Technology Roadmap (4th ed.). Retrieved from: https://www.iata.org/whatwedo/environment/Documents/technology-roadmap-2013.pdf

42. ICAO (2019), Destination green: the next chapter. Retrieved from: https://www.icao.int/environmental-protection/Documents/ICAO-ENV-Report2019-F1-WEB%20%281%29.pdf

43. ICAO (2016), Environmental report: on board a sustainable future. Retrieved from: https://www.icao.int/environmental-protection/Documents/ICAO%20Environmental%20Report%202016.pdf

44. IEA (2020), CO_2 emissions from fuel combustion, IEA Atlas of Energy. Retrieved from: http://energyatlas.iea.org/#!/tellmap/1378539487

45. Jiang H. (2013), "Key findings on airplane economic life", The Boeing Company. Retrieved from: http://www.boeing.com/assets/pdf/commercial/aircraft_economic_life_whitepaper.pdf

46. Latour, B. (1987), *Science in action*, Cambridge: Harvard University Press.

47. Lee D.S., Fahey D.W., Skowron A., Allen M.R., Burkhardt U., Chen Q., Doherty S.J., Freeman S., Forster P.M., Fuglestvedt J., Gettelman A., De León R.R., Lim L.L., Lund M.T., Millar R.J., Owen B., Penner J.E., Pitari G., Prather M.J., Sausen R. and L.J. Wilcox (2021), The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018, *Atmospheric Environment*, 244:117834.

48. Lee D.S., Fahey D.W., Forster P.M., Newton P.J., Wit R.C.N., Lim L.L., Owen B. and R. Sausen (2009), Aviation and global climate change in the 21st century, *Atmospheric Environment*, 43:3520-3537.

49. Masson-Delmotte V., Zhai P., Pörtner H.-O., Roberts D., Skea J., Shukla P.R., Pirani A., Moufouma-Okia W., Péan C., Pidcock R., Connors S., Matthews J.B.R., Chen Y., Zhou X., Gomis M.I., Lonnoy E., Maycock T., Tignor M. and T. Waterfield (eds.) (2018), Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development and efforts to eradicate poverty. Retrieved from: https://www.ipcc.ch/sr15/download/

50. Moore R.H., Thornhill K.L., Weinzierl B., Sauer D., D’Ascoli E., Kim J., Lichtenstern M., Scheibe M., Beaton B., Beyersdorf A.J., Barrick J., Bulzan D., Corr C.A., Crosbie E., Jurkat T., Martin R., Riddick D., Shook M., Slover G., Voigt C., White R., Winstead E., Yasky R.,

Ziemba L.D., Brown A., Schlager H. & B.E. Anderson (2017), Biofuel blending reduces particle emissions from aircraft engines at cruise conditions, *Nature*, 543:411-415.

51. Munda, G. (2008), *Social Multi-Criteria Evaluation for a sustainable economy*, Barcelona: Springer.

52. NLR and SEO (2021), Destination 2050: A route to net zero European Aviation, NLR-CR-2020-510. Retrieved from: https://www.destination2050.eu/wp-content/uploads/2021/02/Destination2050_Report.pdf

53. Novelli, P. (2011), Sustainable Way for Alternative Fuels and Energy in Aviation (SWAFEA), report prepared for the European Commission's Directorate General for Mobility and Transport, Retrieved from: https://www.icao.int/environmental-protection/GFAAF/Documents/SW_WP9_D.9.1%20Final%20report_released%20July2011.pdf

54. Pearce, B. (2020, April 14), COVID-19 updated impact assessment, IATA. [PowerPoint slides] Retrieved from: https://www.iata.org/en/iata-repository/publications/economic-reports/covid-fourth-impact-assessment/

55. Penner J.E., Lister D.H., Griggs D.J., Dokken D.J., and M. McFarland (eds.) (1999), *Aviation and the Global Atmosphere: A special report of the Intergovernmental Panel on Climate Change*, United Kingdom: Cambridge University Press.

56. Pidcock R. and S. Yeo (2016, August 8), “Analysis: aviation could consume a quarter of 1.5C carbon budget by 2050”. Retrieved from: https://www.carbonbrief.org/aviation-consume-quarter-carbon-budget

57. Robson, M. (2020, November 25), “British Airways literally sell their first class china as fans get a bargain”, *Forbes*. https://www.forbes.com/sites/michelerobson/2020/11/25/british-airways-literally-sell-their-first-class-china-as-fans-get-a-bargain/?sh=52fa7d3d421d

58. Sneegas, G. (2019), Making the case for critical Q methodology, *The Professional Geographer*, 72(1):78-87.

59. Soria Baledón M. and N. Kosoy (2018), “Problematizing” carbon emissions from international aviation and the role of alternative jet fuels in meeting ICAO’s aspirational goals, *Journal of Air Transport Management*, 71:130-137.

60. Staples M.D., Malina R., Suresh P., Hileman J.I. and S.R.H. Barrett (2018), Aviation CO_2 emissions reductions from the use of alternative jet fuels, *Energy Policy*, 114(C) :342-354

61. Strand, R. (2017), Post-normal science, in C.L. Spash (ed.), *Routledge handbook of ecological economics: nature and society*, London: Routledge, pp.288-298.

62. TC (2019), Canada's Action Plan to Reduce Greenhouse Gas Emissions from Aviation. 2018 Annual Report, Ottawa. Retrieved from: https://tc.canada.ca/sites/default/files/migrated/2019_2020_ah_03_report_e_accessible.pdf

63. TC (2018), Canada's Action Plan to Reduce Greenhouse Gas Emissions from Aviation. 2017 Annual Report, Ottawa. Retrieved from: https://tc.canada.ca/sites/default/files/migrated/2017annualreport_canadaactionplan_en.pdf

64. TC (2012), Canada's Action Plan to Reduce Greenhouse Gas Emissions from Aviation, Ottawa. Retrieved from: https://tc.canada.ca/sites/default/files/migrated/aviationghgactionpan_eng.pdf

65. Turnpenny J., Jones M. and I. Lorenzoni (2011), Where now for post-normal science? A critical review of its development, definition and uses, *Science, Technology & Human Values*, 36(3):287-306.

66. UCS (2020, August 12), Each country's share of CO_2 emissions. Retrieved from: https://www.ucsusa.org/resources/each-countrys-share-co2-emissions

67. UNFCCC (2020), "Ratification of multilateral climate agreement gives boost to delivering agreed climate pledges and to tackling climate change", UN Climate Change. Retrieved from: https://unfccc.int/news/ratification-of-multilateral-climate-agreement-gives-boost-to-delivering-agreed-climate-pledges-and

68. UNFCCC (2014), Canada's withdrawal from the Kyoto Protocol and its effects on Canada's reporting obligations under the Protocol, CC/EB/25/2014/2. Retrieved from: https://unfccc.int/files/kyoto_protocol/compliance/enforcement_branch/application/pdf/cc-eb-25-2014-2_canada_withdrawal_from_kp.pdf

69. van Dyk S., Ebadian M., Su J., Larock F., Zhang Y., Monnier J., Wang H., Santosa D.M., Olarte M.V., Neuenschwander G., Rotness L.J., Elliott D.C., Drennan C., O'Connor D., Meijerinck O., Burns A., Reid C., García Claro M., Lakeman M. and J. Saddler (2019), Assessment of likely maturation pathways for production of biojet fuel from forest residues, report prepared for GARDN NEC-21 project, Vancouver: University of British Columbia. Retrieved from: http://task39.sites.olt.ubc.ca/files/2019/11/GARDN-NEC-21-ATM-project-final-report-public-release.pdf

70. WBG (2020), *Air transport annual report 2019*, Washington D.C.: World Bank Group.

71. WEF (2020a), Joint policy proposal to accelerate the deployment of sustainable aviation fuels in Europe. Retrieved from: http://www3.weforum.org/docs/WEF_CST_Policy_European_Commission_SAF_2020.pdf

72. WEF (2020b), Clean Skies for Tomorrow: Sustainable aviation fuels as a pathway to net-zero aviation. Retrieved from: http://www3.weforum.org/docs/WEF_Clean_Skies_Tomorrow_SAF_Analytics_2020.pdf

73. Wei, T.T. (2020, September 11), "SIA looks to launch 'flights to nowhere' by end-October to mitigate Covid-19 fallout", *The Straits Times*. Retrieved from: https://www.straitstimes.com/singapore/transport/sia-looks-to-launch-flights-to-nowhere-by-end-october-to-mitigate-covid-19

United Nations regulations, documents, resolutions, working papers and information papers

International Civil Aviation Organization (ICAO)

74. Trends and scenarios on alternative fuels, CAAF/2-WP/06. 07/09/2017. Retrieved from: https://www.icao.int/Meetings/CAAF2/Documents/CAAF.2.WP.006.4.en.pdf

ASTM International standards

75. ASTM D7566, 2020c (2009), Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons, West Conshohocken: ASTM International. Retrieved from: http://www.astm.org.

Annex

FAES Research Ethics Board Office approvals

(including informed consent and data collection forms)

McGill

Research Ethics Board Office
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FAES Research Ethics Board
Certificate of Ethical Acceptability of Research Involving Humans

REB File #: 175-0917

Project Title: Study on stakeholders' perceptions of alternative jet fuels and their role in curbing CO2 emissions from international aviation

Principal Investigator: Mónica Soria Baledón **Department:** Natural Resource Sciences

Status: Ph.D. student **Supervisor:** Prof. Nicolas Kosoy

Approval Period: October 17, 2017 –October 16, 2018

The FAES REB reviewed and approved this project by delegated review in accordance with the requirements of the McGill University Policy on the Ethical Conduct of Research Involving Human Participants and the Tri-Council Policy Statement: Ethical Conduct For Research Involving Humans.

Lynda McNeil
Associate Director, Research Ethics

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* Approval is granted only for the research and purposes described.
* Modifications to the approved research must be reviewed and approved by the REB before they can be implemented.
* A Request for Renewal form must be submitted before the above expiry date. Research cannot be conducted without a current ethics approval. Submit 2-3 weeks ahead of the expiry date.
* When a project has been completed or terminated, a Study Closure form must be submitted.
* Unanticipated issues that may increase the risk level to participants or that may have other ethical implications must be promptly reported to the REB. Serious adverse events experienced by a participant in conjunction with the research must be reported to the REB without delay.
* The REB must be promptly notified of any new information that may affect the welfare or consent of participants.
* The REB must be notified of any suspension or cancellation imposed by a funding agency or regulatory body that is related to this study.
* The REB must be notified of any findings that may have ethical implications or may affect the decision of the REB.

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Informed Consent Form

Project: Study on stakeholders' perceptions of alternative jet fuels and their role in curbing CO_2 emissions from international aviation.
Researcher: Mónica Soria Baledón, Ph.D. candidate,
Department of Natural Resource Sciences.
Contact: monica.soriabaledon@mail.mcgill.ca
Research supervisor: Prof. Nicolas Kosoy, Ph.D.
Contact: nicolas.kosoy@mcgill.ca

Dear Madame/Sir/Dr./Prof.:

This research project aims at gaining a deeper understanding of the current and future role of alternative jet fuels in curbing net CO_2 emissions to meet ICAO's goals for 2020 and 2050. It is a central piece of my doctoral dissertation and like all such works, the finished text will be available to the public.

As a key stakeholder within the aviation community, your participation in this project is highly valued. Also, it is entirely voluntary and you may choose to withdraw at any point from it and/or not answer the questions you do not want to.

The study is divided into two parts and completion takes approximately 30 minutes. In the first part, you will be asked to rank a list of statements according to your level of agreement/disagreement with each of them. At any stage, you can re-rank these statements until you feel they are fully representative of your personal viewpoint.

The second part consists of a short interview to provide the researcher with the context behind your ranking choices, which will be audio recorded solely to ensure accuracy.

The audio will be destroyed once the interview has been transcribed and all collected data will be reported in such a way as to make direct association with yourself impossible. No third-parties will have access to any of the data collected through this research and all electronic materials will be kept on a password-protected computer.

Once again, thank you very much for your participation. I will be sharing with you the results of this project by e-mail as soon as they become available.

Should you have any questions about this project, you can reach me at the coordinates listed above at your earliest convenience.

Consent: I agree to be audio recorded ____ YES ____ NO

I have read the above information and I agree to participate in this study.

Printed name: ______________________

Signature: ________________________

Date: _____________________________

If you have any questions or concerns about your rights or welfare as a participant in this research study, please contact the Manager, Research Ethics at +1 (514) 398-6831 or at Lynda.mcneil@mcgill.ca.

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Study on stakeholders' perceptions of alternative jet fuels and their role in curbing CO_2 emissions from international aviation

Participant's name: ___________________________
Title: ____
Organization: __________________________________
Contact: ______________________________________

Part I

Instructions: Please take a couple of minutes to read all the statements presented below. Then rank each of them according to your level of agreement/disagreement by selecting one option in the scale. At any stage, you can re-rank these statements until you feel they fully represent your viewpoint on the topic. Part I takes approximately 15 to 20 minutes to complete.

1. Air travel facilitates face-to-face contact, which is desirable and necessary for the establishment and maintenance of social, economic and political linkages.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

2. The shift from air travel towards less environmental harmful modes of transportation will only stand a chance once airfares fully incorporate the true environmental costs of air transport.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

3. The multiple roles played by governments worldwide in the civil aviation sector hinder its capacity to grow sustainably.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

4. The rapidly-growing demand for mobility simply cannot be accommodated in any sustainable way. Absolute CO_2 emissions will continue to rise.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

5. Taking at least one international holiday each year, increasingly to long-haul destinations, has turned from an aspiration to an expectation.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

6. Governments and the aviation industry are heavily investing in R&D in order to break away from the current technological lock-in around fossil jet and alternative drop-in fuels.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

7. No State seems to be ready for any substantial sacrifices in the economy or level of employment to protect the environment.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

8. Short-haul flights should be substituted for by lower-carbon modes of transportation to the largest degree possible.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

9. Resilience of the international aviation sector results from a very robust air travel demand, particularly from business users. Regulatory measures will not disrupt that demand unless prices would substantially increase.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

10. The international aviation community has historically downplayed the sector's environmental impacts while overemphasizing the technological efficiencies introduced over the years.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

11. Aircraft and engine design is more or less a perfected technology.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

12. The aviation sector has the responsibility to inform travelers about the environmental impacts of air transport and tourism, and to raise awareness about their options for travelling more sustainably.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

13. Aircraft design is conservative and risk averse to radical change.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

14. ICAO's determination to downplay aviation's contribution to global GHGs emissions has made it much more difficult for its Member States to understand the urgency to act.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

15. Even if existing economic barriers are removed, alternative fuels are unlikely to become available in sufficient quantities to play a significant role in reducing GHGs emissions from international aviation.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

16. Hypermobility, particularly for business travel, should be acknowledged as a policy issue and addressed within aviation's climate action discussions.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

17. Since international aviation's growth will mainly take place in developing countries, they should comply with climate change obligations in the same way developed countries are obliged to.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

18. There is little awareness and understanding within the aviation sector of the potential environmental impacts and externalities of air transport activities beyond fuel usage.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

19. Users of air travel services experience the benefits of aviation but remain largely unaware of its negative environmental impacts.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

20. There is no indication that alternative fuels will be available in sufficient quantities at competitive prices to meet the total aviation jet fuel requirements for attaining the CO_2 reduction goals by 2050.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

21. Without legal and policy frameworks suitable to address the current and future challenges imposed by climate change, the international aviation sector will be unable to reduce its CO_2 emissions to attain its climate goals.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

22. A better understanding of alternative jet fuels' potential to reduce GHGs emissions is needed for more informed decision-making within the international aviation community and ICAO's Member States.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

23. Flexibility in cost structures allows airlines to accommodate fuel cost volatility.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

24. Participation of civil society in climate change discussions and the formulation of environmental policy within ICAO - and within certain of its Member States - is highly exclusive and restrictive.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

25. Alternative jet fuels have the potential to reduce the radiative effect of atmospheric aircraft contrails and contrail-induced cirrus clouds as a result of cleaner combustion than conventional Jet A/A-1 fuels.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

26. Market distortions exist in international aviation even in the absence of environmental obligations.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

27. Little involvement of Member States from developing countries in ICAO's technical work has and will continue to create disagreement for decision-making the moment it reaches the political arena.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

28. Alternative jet fuels certified under ASTM Int.'s D7655 or an equivalent standard are safe to use in aircraft and in all conventional Jet A/A-1 fueling infrastructure.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

29. ICAO's MBM may hinder the development and adoption of net emissions reduction measures, both operational and technological.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

30. Making Action Plans mandatory and auditable by ICAO will facilitate compliance by Member States with the global MBM scheme.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

31. Alternative jet fuels should only be considered sustainable if they demonstrate compliance with the social, environmental and economic requirements of third-party certifiers.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

32. Business air travel remains largely overlooked and unregulated despite of its significantly larger environmental impact per capita compared to commercial air travel.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

33. The CO_2 mitigation potential of alternative jet fuels is reliant on the net emission reductions from biomass production, fuel refining and transportation for delivery to the end-user.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

34. ICAO's MBM is a tool to induce coordination among different regimes, avoid additional market distortions and shield the international aviation industry from additional financial burdens and redundant compliance.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

35. Large-scale production of alternative jet fuels can aggravate the direct and indirect environmental impacts linked to intensive agriculture of dedicated bioenergy feedstocks (i.e. crops, lignocellulosic biomass, algae).

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

36. The Chicago Convention does not provide anymore an appropriate framework to address the current and emerging challenges posed by climate change.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

37. Future growth in demand for air travel will outpace the technological and operational efforts to reduce international aviation's contribution to climate change.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

38. The distinction of edible and non-edible crops as feedstock for alternative jet fuels does not address the issue of land use, as renewable fuels made from non-edible crops - including cellulosic species - can displace forests, grazing land or directly compete with agricultural land for food production.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

39. Production of alternative jet fuels does not have demonstrable social spillovers, as the required economies of scale prevent subsistence-to-medium farming operations to participate.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

40. The 2008's steep increase in world food prices was a multifactorial crisis that was the result of severe drought, high oil prices, financial speculation in grains and the expansion of ethanol production in the US. Alternative fuels' production from edible crops cannot be blamed alone as the basis of food scarcity, as it is also the result of distributive inequality.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

41. Emerging bioenergy feedstocks are preferred over the edible and non-edible agronomic crops despite of the prevailing knowledge gaps on their potential environmental impacts, including indirect land use changes, risks of biological invasion, biodiversity loss, etc.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

42. Third-party certification frameworks (i.e. RSB) lack more robust data to completely inform decision-making on the sustainability of alternative jet fuels.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

43. If airfares were to reflect the true environmental costs of flying, air travel would become inaccessible to millions since they would be at least two to three times higher than they are at present.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

44. Although alternative jet fuels can be produced from different type of "residues" (i.e. agricultural, municipal and industrial), their supply chains are not yet established to make them cost-competitive.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

45. World refining capacity of alternative jet fuels is constrained by economic barriers, policy uncertainty and technological limitations throughout the whole supply chain that deter investment to move production into the commercial stage.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

46. No alternative fuel can be called a biofuel since every stage in the supply chains of biomass and fuel production involves fossil fuel inputs: petroleum-derived fertilizers, herbicides and pesticides, mechanical harvesting and several stages of fuel refining and transportation.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

47. Virtually all carbon capture or carbon reduction schemes *are* certified. The problem is that many sustainability certification arrangements are farcical. They are institutional lies, established to allow greedy people to exploit honest people and the world’s desire for climate change action. Having valid sustainability certification criteria and processes would address this issue.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

48. The use of certain types of residual materials for alternative jet fuel production can create significant market distortions and externalities. For example, used cooking oil (UCO) has become a pricey commodity traded at US$400 per tonne, perpetuating wasteful food processing techniques of edible oils.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

49. Preference by the international aviation community for non-edible bioenergy crops and residual materials as feedstocks for alternative jet fuels is essentially political and does not have solid scientific foundations.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

50. Responsible and sustainable sourcing of a small batch of alternative jet fuel for a single flight is commendable. Finding sufficient land to supply a sizeable portion of the present and future world's jet fuel use is a different matter.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

51. Air transport users are generally unaware of the advantages and drawbacks of alternative jet fuels. Since social acceptance may affect a technology's market success, public understanding of alternative fuel technology use in aviation should be pursued.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

52. Current R&D efforts should steer towards fully-electric aircraft and away from drop-in alternative jet fuels.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

53. Certification of renewable/green diesel as a blending component of fossil jet fuel under ASTM Int.'s D7566 and equivalent standards can significantly increase the participation of alternative fuels in meeting the industry's CO_2 reductions targets for 2020 and 2050.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

54. Most types of residual materials require extensive pretreatment due to their poor quality, cancelling the environmental benefits of using them as feedstocks for alternative jet fuels' production.

Strongly disagree	Disagree	Somewhat disagree	Indifferent	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

Part II

Instructions: Please read carefully the following questions before proceeding to answer them. Part II takes approximately 10 minutes to complete.

a. In a few words, what is your perception of alternative jet fuels and their potential and/or caveats to curb the net CO_2 emissions from international aviation?

b. Is there any particular statement you would like to comment or elaborate on?

c. Is there any missing aspect of the topic covered in this study that you feel is relevant to your position?

Once again, thank you.

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