Master's thesis
Master Sustainable Development

Systems Thinking for Degrowth

The case of European aviation

BY

Anya Al-Salem

SUPERVISOR

Dr. Robert Harmsen
Assistant Professor
Copernicus Institute of Sustainable Development
Utrecht University

SECOND ASSESSOR

Dr. Giuseppe Feola
Associate Professor
Copernicus Institute of Sustainable Development
Utrecht University

45 ECTS
January 15, 2024

Universiteit Utrecht

Abstract

Degrowth is a burgeoning social movement and academic field calling for a democratic reduction in material and energy throughput in order to address environmental issues, such as climate change, while ensuring well-being for all. The research agenda on degrowth has grown significantly in recent years; however, there are some important limitations of degrowth policy literature that inhibit the development of effective degrowth transition strategies. One of these limitations is the prevalence of 'policy dropping', which refers to a lack of analytical scrutiny behind the selection of certain degrowth policies over others. A valuable approach to addressing this issue involves systems thinking, which uncovers the feedback loops driving system behaviour and, consequently, provides a foundation to evaluate the systemic effects of degrowth policy proposals and identify key policy intervention points.

The present research builds on existing degrowth policy literature by using systems thinking tools and concepts to lay the analytical foundation for the strategic selection of degrowth policies, thereby contributing to the development of degrowth transition strategies. The novelty of the present study lies in its focus on the European aviation sector, which is particularly relevant to degrowth discourse due to its high levels of projected growth and lack of viable 'green growth' solutions. In order to fulfil its aim, the present research identifies (1) the dominant feedback loops in the European aviation system and (2) leverage points for degrowth of European aviation.

Based on 25 expert interviews and an expert workshop, the author presents a causal loop diagram illustrating 15 feedback loops explaining the growth in European aviation activity. Based on these feedback loops, the author identifies two variables — aviation industry lobbying and airline ticket prices — that the author argues serve as strategic intervention points for degrowth policies. This study provides important insights for the development of degrowth transition strategies for European aviation and illustrates the usefulness of systems thinking to degrowth policy discourse in general. Potential avenues for future research include applying the methodology of the present study to other sectors and building on the present study to develop further contributions to degrowth policy for European aviation, for example by assessing degrowth policy interactions.

Table of Contents

List of Tables

List of Figures

List of Appendices

Acknowledgements

I would like to express my deep gratitude to my supervisor, Dr. Robert Harmsen, for his unwavering support and encouragement throughout the entire thesis process. I would also like to sincerely thank all my research participants for generously taking the time out of their busy schedules to contribute to my research. I was joyfully overwhelmed by all the positive feedback and support I received from the people I reached out to, even those I had never met before. Finally, I would like to extend heartfelt thanks to my dear family, friends, and peers who provided invaluable moral support and were always there to listen and share their thoughts. Particularly, I am very grateful to my mother, Viktoria Olskaia, who thoroughly proofread my research proposal and final draft and was my greatest support through all the stages of my thesis, despite being on another continent.

1. Introduction

1.1. Context

Based on current trends, average global temperatures are expected to exceed a 1.5°C increase above pre-industrial levels as early as 2033, causing unprecedented and potentially irreversible damage to human societies and natural ecosystems (Diffenbaugh and Barnes, 2023; IPCC, 2023). Therefore, the coming decade marks a critical period for making rapid and deep reductions in anthropogenic greenhouse gas (GHG) emissions (IPCC, 2023).

The dominant approach to mitigating the climate impacts of human activity focuses on supply-side solutions, such as efficiency improvements, renewable energy development, and technological innovation, while supporting the continued growth of economic activity (Dale et al., 2016). However, there is little evidence to support this 'green growth' narrative (i.e., the idea that economic growth can be decoupled from environmental degradation; Hickel and Kallis, 2019), combined with a growing awareness of the importance of demand-side measures in reducing GHG emissions across sectors (Creutzig et al., 2022).

One alternative to the discourse of 'green growth' is that of 'degrowth' — a burgeoning academic field and social movement challenging the primacy of economic growth as an indicator of prosperity and calling for "a democratically deliberated absolute reduction of material and energy throughput, which ensures well-being for all within planetary boundaries" (Barlow et al., 2022, p. 11). Degrowth rhetoric has gained significant traction in academia and permeated the political sphere, as evidenced by the magnitude of the 2023 Beyond Growth Conference at the European Parliament in Brussels, during which degrowth was a central theme (BSR, 2023).

1.2. Research gap

Although the research agenda on degrowth has grown significantly in recent years, including a proliferation of associated policy proposals, a recent review reveals some important gaps in academic degrowth policy discourse to date, which inhibit the development and implementation of effective degrowth transition strategies (Fitzpatrick et al., 2022). One prominent issue identified by the review authors is the prevalence of 'policy dropping', which refers to the practice of mentioning policies "without much analytical effort made to connect them with the issues at hand" (p. 8). The authors hypothesise that certain degrowth policies tend to be referenced more often than others simply because of their pre-existing popularity and warn that "[t]his fashion-like trend in picking policy proposals may lead to biases where high-impact changes find themselves pushed to the periphery of the agenda" (p. 9). Therefore, there is a critical need for research that supports the informed selection of degrowth policies, thereby improving the strategic relevance of degrowth policy literature. A more extensive introduction to degrowth strategy and policy concepts can be found in Section 3.2, and Section 2.2 includes a brief overview of the current state of academic degrowth policy research.

One approach to strategically selecting degrowth policies involves the application of 'systems thinking' — a perspective, vocabulary, and set of tools that interprets reality in terms of 'systems', which are "interacting, interrelated, or interdependent parts that form a complex and unified whole that has a specific purpose" (Kim, 1999, p. 2). A core tool of systems thinking is the causal loop diagram (CLD), which provides a conceptual overview of salient reinforcing and balancing processes — collectively called 'feedback loops' — that explain system behaviour (Kim, 1999). These feedback loops consist of links representing causal relationships between system variables (i.e., quantities that change over time). A CLD renders an integrated, holistic overview of a complex issue and, thus, can be used to evaluate the systemic effects of potential policy interventions (as illustrated by Videira et al., 2014) and identify key intervention points (i.e., 'leverage points'; Roxas et al., 2019). Thus, a systems thinking approach can provide a robust foundation for strategic policy selection and the subsequent development of degrowth transition strategies. The systems thinking concepts introduced in this paragraph are presented in further detail in Section 3.1.

Notable academic studies applying systems thinking to degrowth policy include Videira et al. (2014), Đula et al. (2019), and Parrique (2019). While these works adopt a broad sectoral and geographical scope, there are few studies applying systems thinking to degrowth policy targeting specific sectors. Such research can strengthen the strategic effectiveness of degrowth discourse by yielding more specific policy insights and recommendations (Barlow et al., 2022). Therefore, the present research focuses on the European aviation sector, which is introduced in the following section. To the author's knowledge, research exploring degrowth pathways for European aviation from a systems thinking perspective is currently lacking in the academic literature.

1.3. Case study: European aviation

The European aviation sector is a useful case study for degrowth policy research due to its high levels of (projected) growth and corresponding climate impact. Between 2005 and 2019, European aviation traffic and corresponding GHG emissions grew by 67% and 24%, respectively (Transport & Environment, 2022b). Despite the sharp decline in aviation activity in 2020 resulting from the COVID-19 pandemic, European air traffic reached 77% of 2019 levels in 2022 (Eurocontrol, 2022b) and is projected to reach 16 million flights by 2050, which would be a 44% increase compared to 2019 levels (Eurocontrol, 2022a). Under an ambitious baseline scenario including fuel efficiency improvements from technology and operations, carbon dioxide (CO_2) emissions from aviation are projected to increase by 36% by 2050 relative to 2019 levels (Transport & Environment, 2022b). Moreover, the climate impacts of aviation are exacerbated by the sector's non-CO_2 effects: in addition to CO_2, aircraft engines emit other greenhouse gases and particulate matter (soot), which affect atmospheric physical and chemical properties, yielding a net warming effect that may be up to three times worse than that of CO_2 alone (Transport & Environment, 2022a).

Aside from aviation's climate impacts, which are global, the sector has detrimental local effects — particularly noise, which has been found to cause community annoyance, sleep disruption, adverse effects on children's academic performance, and potentially increased risk of cardiovascular disease for people residing near airports (Basner et al., 2017). Furthermore, aviation contributes to climate injustice — only a small proportion of the global population has ever flown, and an even smaller 'hypermobile elite' of frequent flyers contributes a majority of emissions from aviation, while most of the detrimental environmental impacts of aviation are borne by disadvantaged people and communities (Stay Grounded, 2019). While the author acknowledges the multifaceted nature of the aviation problem, due to time and resource constraints the present research focuses primarily on the climate impacts of the sector.

In order to support Europe's economy-wide ambition to become climate-neutral, the European aviation sector has committed to net-zero CO_2 emissions from all flights within and departing from the EU by 2050 (NLR and SEO Amsterdam Economics, 2021). The sector's approach to mitigating its climate impacts focuses mainly on technological advancements while assuming continued volume growth (NLR and SEO Amsterdam Economics, 2021). However, a number of researchers and advocacy groups highlight the problematic nature of such 'green growth' solutions for aviation and identify an absolute reduction in aviation activity as a crucial element of effectively addressing the climate impacts of the sector (e.g., Stay Grounded, 2019; Köves and Bajmócy, 2022; Transport & Environment, 2022b; Gössling and Humpe, 2023). This argument is strengthened by the sustainability and feasibility challenges associated with the prevalent 'green growth' solutions for the sector, which are elaborated on in Section 2.1.3. Furthermore, there is a small but growing body of literature explicitly linking aviation and degrowth, which is explored in Section 2.1.2.

The present research defines European aviation as all flights departing from airports located in the EU-27 (NLR and SEO Amsterdam Economics, 2021). Due to resource and time constraints, the research focuses exclusively on commercial passenger aviation due to its disproportionately high contribution to emissions from European aviation: according to a reference scenario in a report by the Netherlands Aerospace Centre (NLR) and SEO Amsterdam Economics (2021), emissions from passenger flights accounted for 95% of emissions from European commercial aviation in 2018. Consequently, the research scope excludes freight, military, and private aviation. Furthermore, the 'European aviation system' is conceptualised as the variables, causal relationships, and resulting feedback loops that contribute to the growth in European aviation activity.

1.4. Research objectives, questions, and outline

The present research aims to add to the degrowth policy literature by laying the analytical foundation for the development of effective degrowth transition strategies for European aviation. The research aims to address the following main research question:

How can a systems thinking perspective contribute to the strategic selection of degrowth policies for European aviation?

The research aims to answer the main research question through the following sub-questions:

1. *What are the dominant feedback loops in the European aviation system?*

   First, the research presents a CLD illustrating feedback loops between key system variables within the European aviation system.

2. *What are leverage points for degrowth of European aviation?*

   Based on the feedback loops, the author identifies variables representing leverage points within the European aviation system, which can serve as strategic intervention points for the implementation of degrowth policies.

The thesis is structured as follows. Chapter 2 elaborates on the ideas presented in Chapter 1 by providing key background information on degrowth (of aviation) and the state of degrowth policy literature. Next, Chapter 3 addresses key theoretical concepts related to systems thinking and degrowth strategy and policy. Chapter 4 describes the methods used to address the research questions guiding the present research, and Chapter 5 presents the results of the research, structured by research sub-question. Subsequently, Chapter 6 uses the key findings of the research to answer the main research question. Finally, Chapter 7 addresses the contribution of the present research to the scientific literature, presents methodological limitations of the research, and provides recommendations for future research.

2. Literature Review

The present chapter provides important background information on the topic of degrowth, specifically within the context of (European) aviation, justifying the selection of the political stance (i.e., in support of degrowth) and case study adopted in the present research. Furthermore, this chapter expands on the gaps within the research on degrowth policy.

2.1. Degrowth (of aviation)

This section elaborates on the social movement and academic field of degrowth and its relevance to aviation.

2.1.1. Contextualising degrowth

Adding to the definition presented in Section 1.1, "[d]egrowth is a planned reduction of energy and resource throughput designed to bring the economy back into balance with the living world in a way that reduces inequality and improves human well-being" (Hickel, 2020, p. 2). It is based in Europe and exists within a wider sphere of global movements with a similar goal, such as *buen vivir* (Latin America) and *ecological swaraj* (India), all of which strive for a good life beyond economic growth, capitalism, and development (Kothari et al., 2014).

One of the fundamental arguments of degrowth is that there is a lack of empirical evidence supporting 'green growth', thereby necessitating a shift to a system that is not dependent on economic growth (Hickel and Kallis, 2019). According to prominent degrowth scholar Jason Hickel (2020), "[d]egrowth calls for the reversal of the processes that lie behind growth [through] disaccumulation, decommodification, and decolonization" (p. 3). In place of a growth-centred society, degrowth visions are based on values such as autonomy, care, conviviality, direct democracy, equity, commoning, and sufficiency (Barlow et al., 2022). Moreover, degrowth celebrates "a rainbow of knowledges, cosmologies, and vital worlds, conceptualised as components of a pluriverse"; therefore, it is crucial for degrowth policy discussions to accommodate a diversity of approaches and positions (Barlow et al., 2022, p. 182).

Importantly, degrowth efforts focus on a reduction in excess resource and energy use specifically in the Global North (Hickel, 2020; Barlow et al., 2022). Advocates of the movement argue that resource consumption in the Global North exploits communities and damages ecosystems primarily located in the Global South; therefore, "degrowth in the North represents a process of decolonization in the South" (Hickel, 2020, p. 5). Thus, the present thesis's focus on degrowth in Europe, which is generally considered part of the Global North, aligns with the principles of degrowth.

2.1.2. Aviation and degrowth

'Degrowth of aviation' refers to a call to reduce flying, primarily in order to mitigate the environmental impacts of the sector (Stay Grounded, 2019). A foundational piece summarising the key arguments and measures for degrowth of aviation is the *Degrowth of Aviation* report by Stay Grounded (2019) — a grassroots network dedicated to promoting alternatives to aviation — which is the outcome of a conference on the topic, which took place in Barcelona in 2019. Within academic literature, there is a small but growing number of papers explicitly applying a degrowth perspective to aviation. For example, Köves and Bajmócy (2022) present a degrowth-based critique of the global aviation industry's *Waypoint 2050* report, which outlines the sector's strategy to achieve net-zero CO_2 emissions by mid-century under a growth-based model. In a similar vein, Katz-Rosene and Ambe-Uva (2023) explore the development of a degrowth-centred multilateral environmental agreement for global aviation. Moreover, in the recently published book *Contesting Aviation Expansion*, authors Griggs and Howarth (2023) criticise airport expansion in the UK and promote a 'post-aviation future' based on the related principles of sufficiency, degrowth, and alternative hedonism.

A particularly salient element of the discourse around degrowth of aviation is ensuring a just transition for aviation workers. Potential avenues for such a transition are discussed in Chapter 17 of *Degrowth & Strategy* by Barlow et al. (2022), as well as Part IV of *A European Just Transition for a Better World* (Holemans, 2022). Moreover, the campaign group Safe Landing advocates for long-term employment for aviation workers, arguing that the unmitigated growth of the sector poses the largest threat to aviation workers' job security (Safe Landing, n.d.).

2.1.3. The problems with 'green growth' of aviation

The degrowth argument for aviation largely rests on the lack of empirical evidence supporting the rapid and effective mitigation of the climate impacts of the sector through decarbonisation measures and technologies alone, especially in the short term, without reducing the overall amount of air traffic. Additionally, certain decarbonisation measures supported by the aviation sector have problematic environmental and social implications. This section delves into the limitations of the 'green growth' approach to aviation (as presented in the *Destination 2050* pathway, introduced below), further justifying the degrowth stance of the present research.

In order to meet its goal of net-zero CO_2 emissions by 2050, the European aviation sector has developed a decarbonisation pathway titled *Destination 2050*, which encompasses four pillars: (1) improvements in aircraft and engine technology; (2) improvements in air traffic management and aircraft operations; (3) drop-in sustainable aviation fuel (SAF); and (4) economic measures, namely, emission trading and carbon offsetting (NLR and SEO

Amsterdam Economics, 2021). Notably, while the report acknowledges that the costs of these measures are expected to reduce projected air travel demand, the number of flights is still expected to grow by 1.4% each year on average, reaching 12.4 million flights in 2050 – a 12% increase compared to 2019 levels (NLR and SEO Amsterdam Economics, 2021).

The first pillar, improvements in aircraft and engine technology, encompasses fuel efficiency improvements as well as the introduction of (hybrid-)electric and hydrogen-powered aircraft. These measures are projected to account for a 37% reduction in European aviation's CO_2 emissions in 2050 relative to a reference scenario. However, an analysis of past trends indicates that potential emissions savings resulting from improvements in fuel efficiency have always been offset by an increase in overall aviation activity; illustratively, despite a decline in global aircraft fuel consumption per passenger kilometre of over 70% since the 1960s, emissions from the sector have grown significantly during this time period, as passenger kilometre volumes have increased more quickly than efficiency gains (Peeters et al., 2016). Moreover, while the grams of CO_2 per passenger kilometre for European aviation decreased by 28% between 2005 and 2019 (EASA, 2022), total emissions from the sector grew by 24% during this time period (Transport & Environment, 2022b). This suggests that further improvements in fuel efficiency are unlikely to yield a reduction in absolute emissions from aviation without a simultaneous stabilisation or decrease in overall aviation activity.

Furthermore, while *Destination 2050* emphasises the role of battery-electric and hydrogen aircraft in decarbonising the sector by 2050, there is a large amount of uncertainty surrounding the readiness and scalability of these technologies and, subsequently, their potential contribution to the near-term decarbonisation of aviation. Although battery-electric aircraft powered by renewable electricity is carbon neutral in principle, there are still substantial advancements that need to be made in order for this technology to play a significant role within air passenger transport before mid-century (Gössling and Humpe, 2023). The main issue is that aircrafts require energy sources with high gravimetric and volumetric energy density (Davis et al., 2018), and current battery technology can accommodate just a fraction of the energy density of kerosene (Viswanathan and Knapp, 2019). Moreover, the large-scale implementation of battery-electric aircraft would require significant changes to airport infrastructure (Gössling and Humpe, 2023).

Similarly, while it may be possible for hydrogen-powered aircraft to contribute to aviation emissions reduction in the long term, it is unlikely to enter commercial aviation prior to 2050 (Waddington et al., 2021). Major barriers to the rapid commercial scalability of hydrogen-powered aircraft include in-aircraft hydrogen storage, aircraft redesign and turnover, and the need for new infrastructure for production, distribution, and bunkering (Huete et al., 2021; Gössling and Humpe, 2023). Therefore, while battery-electric and hydrogen-powered aircraft have the potential to contribute to aviation emissions reduction in the long term (i.e., in the second half of the century), it is unlikely for these technologies to contribute significantly to the decarbonisation of European aviation by mid-century, as projected in *Destination 2050*.

Another decarbonisation technology proposed by *Destination 2050* is drop-in sustainable aviation fuel (SAF), which the report projects to account for a 34% reduction in European aviation's CO_2 emissions in 2050 relative to the reference scenario (NLR and SEO Amsterdam Economics, 2021). One of the main benefits of SAF is that it does not require new aircraft or airport infrastructure (Gössling and Humpe, 2023); however, the large-scale utilisation of SAF faces some significant sustainability and feasibility constraints. Biomass-based SAF has been found to have complex social and ecological sustainability implications, which vary according to the type of biomass feedstock used for its production (Darda et al., 2019; Nazari et al., 2021), and higher production costs than conventional jet fuel (Dahal et al., 2021). While non-biogenic (i.e., synthetic) SAF mitigates the sustainability issues associated with biomass-based SAF when derived from renewable energy, synthetic fuels are currently only available in experimental stages, and their market entry prices are expected to be between two and six times greater than those of conventional jet fuels (Schmidt et al., 2018), inhibiting the rapid upscaling of non-biogenic SAF.

The last pillar of the decarbonisation pathway proposed in *Destination 2050* is economic measures, particularly emissions trading and offsetting. Since 2012, the EU Emissions Trading System (ETS) covers emissions from intra-EEA flights; however, it does not apply to international flights (which produce the most emissions), largely as a result of aviation industry lobbying against stringent climate policy (InfluenceMap, 2021). Rather, emissions from international flights are addressed under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), which was developed by the International Civil Aviation Organisation (ICAO), the United Nations body responsible for international aviation, and went into effect in 2016 (Lyle, 2018). However, CORSIA has been regarded as entirely ineffective in reducing emissions from global aviation as the scheme does not account for emissions below 2019 levels or non-CO_2 emissions, is legally non-binding, and relies on carbon offsetting (i.e., compensating for CO_2 emissions by funding emissions-saving projects elsewhere), which is often based on flawed assumptions, occurs at the expense of ecosystems and communities in the Global South, and shifts efforts away from more effective decarbonisation measures (Finance & Trade Watch, 2017; Lyle, 2018; Warnecke et al., 2019; Scheelhaase and Maertens, 2020).

This section illustrates that the 'green growth' narrative promoted by the European aviation industry largely relies on measures that are unlikely to contribute to significant reductions in emissions from aviation, especially in the short term. Moreover, some of these measures – such as biomass-based SAF and carbon offsetting – can cause additional social and environmental problems. Therefore, in order to rapidly and effectively mitigate the climate impacts of European aviation, it is crucial to reduce the absolute amount of aviation activity, which is the focus of the present study, while continuing to develop technologies that are both socially and environmentally sound and can play a more significant role in the long-term decarbonisation of the sector.

2.2. Degrowth policy

This section provides an overview of the academic degrowth policy literature, with special attention to research adopting a systems thinking perspective.

The most recent comprehensive review of degrowth policy literature was conducted by Fitzpatrick et al. (2022). This review builds on the work of Cosme et al. (2017) and Parrique (2019), which constitute the only other existing inventories and analyses of academic degrowth policies. In addition to the problem of 'policy dropping' discussed in the Section 1.2, Fitzpatrick et al. (2022) identified the following limitations within academic degrowth policy discourse: a lack of precision in degrowth policy proposals, limited consideration of 'unconscious' or 'enabling' policies (i.e., the changes that are needed to create the conditions for successfully implementing the proposed policies), and insufficient attention to potential interactions (i.e., synergies and conflicts) between degrowth policy proposals.

Within the degrowth literature, there are several studies that have explored degrowth policy through a systems thinking lens. Notably, Đula et al. (2019) conducted a 'systems dynamics' analysis (i.e., a modelling method for building computer simulations of complex systems) to investigate the underlying causal structures of three degrowth policy proposals — (1) basic and maximum income, (2) work-sharing, and (3) job guarantee — and assess the possible outcomes of these policies in developed countries. Furthermore, in Chapter 12 of his PhD dissertation, Parrique (2019) developed CLDs to investigate the effects of degrowth policies across nine 'policy bundles' (e.g., sharing wealth, democratic ownership of business, and stewardship of nature), as well as the effects of the interactions between these policies. Another key study applying systems thinking to degrowth policy analysis was conducted by Videira et al. (2014), who use CLDs of the social, ecological, and economic sectors to evaluate the systemic effects of degrowth policies and identify leverage points.

While the studies described in the previous paragraph adopt a broad scope, there is a small number of studies that apply systems thinking to degrowth in relation to specific fields and/or sectors. One such study by Otero et al. (2022) proposes steps to develop degrowth scenarios for biodiversity, including identifying leverage points and key social-ecological feedbacks. Moreover, Chakori et al. (2021) developed a CLD illustrating variables and feedback loops that influence the use of single-use food packaging and, subsequently, identify a shift towards an economic degrowth framework as a potential solution to the food packaging problem. Similarly, Chakori et al. (2022) use systems thinking to explore drivers of food packaging use and propose degrowth policies as important contributors to a reduction in food packaging.

3. Theoretical Concepts

This chapter elaborates on the main theoretical concepts and frameworks employed in the present research, divided into the following two categories: (1) systems thinking and (2) degrowth strategy and policy.

3.1. Systems thinking

In this section, the author goes into further detail regarding two elements of systems thinking that are fundamental to the present research: (1) CLDs and (2) leverage points.

3.1.1. Causal loop diagrams

A CLD is a conceptual map ('systems map') whose primary function is illustrating the feedback loops in a system, which are made up of causal relationships between system variables and explain the mechanisms of a particular problem (Kim, 1999). In a CLD, the causal relationships between variables are represented by causal links, which are arrows illustrating the causal effect of one variable on another (Figure 1). A positive effect (represented by a '+') indicates that the variables change in the same direction (i.e., more of one variable leads to more of another variable, or less of one variable leads to less of another variable). Conversely, a negative effect (represented by a '-') indicates that the variables change in opposite directions (i.e., more of one variable leads to less of another variable, or less of one variable leads to more of another variable).

A feedback loop occurs when two or more causal links between system variables form a closed loop, which can be either 'reinforcing' or 'balancing' (Figure 1; Kim, 1999). A reinforcing feedback loop occurs when the product of the signs of all the effects is positive, thus reinforcing a given initial change in a variable and leading to exponential system change. Alternatively, in the case of a balancing feedback loop, the product of the signs of all the effects is negative, thus self-correcting or balancing a given initial change in a variable and leading to system stability. A CLD usually contains several overlapping feedback loops.

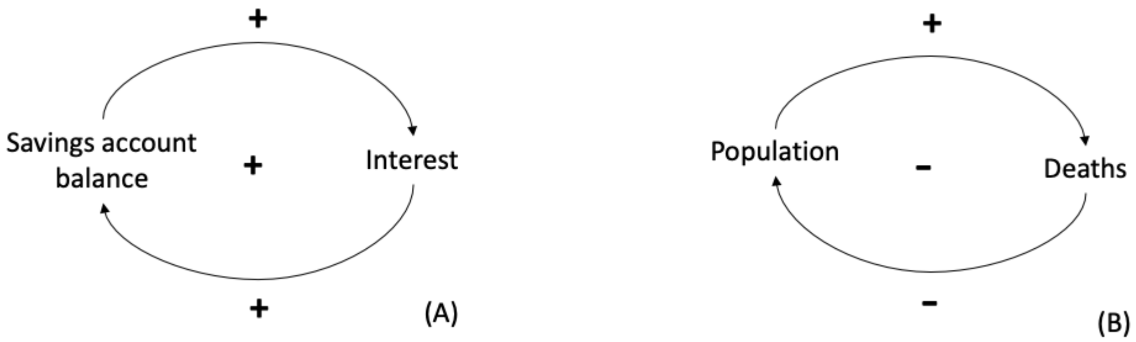

Figure 1. An example of a reinforcing (A) and balancing (B) feedback loop, as they are depicted in a CLD. In A, the more savings there are on a bank account, the higher the interest earned on these savings, which consequently leads to more savings. The product of the signs of the effects in this feedback loop is positive (+), which means this is a reinforcing feedback loop. In B, the greater the population of an area, the greater the number of deaths, which consequently results in a lower population. The product of the signs of the effects in this feedback loop is negative (-), which means this is a balancing feedback loop.

It is important to note that CLDs provide a *simplified* representation of a complex issue; therefore, rather than accounting for all the possible variables and causal relationships in a system, CLDs focus on the most salient elements. Moreover, CLDs are not prescriptive; rather, they provide a useful tool for assessing how potential changes in one part of a system (i.e., systemic interventions) might influence the behaviour of the system as a whole.

3.1.2. Leverage points

Leverage points are "places within a complex system […] where a small shift in one thing can produce big changes in everything" (Meadows, 1999, p. 1). Within a CLD, a leverage point constitutes a variable where an intervention can produce significant systemic effects (Roxas et al., 2019). Meadows (1999) provides a framework for identifying and ranking leverage points, ranging from 'constants, parameters, numbers' (least effective) to 'the power to transcend paradigms' (most effective). Building on Meadows' framework, Kieft et al. (2020) propose three criteria for identifying leverage points in a system: (1) system change potential, (2) resistance to change, and (3) physical constraints. The authors argue that a systemic intervention point (i.e., variable) is a leverage point if its system change potential is significant, while it is also possible to overcome barriers to intervening on the variable. Roxas et al. (2019) support these criteria, stating that, within a CLD, a leverage point (1) "[i]s a common cause to multiple effects", (2) "[c]an be influenced by an intervener", and (3) "is the root cause [...] (i.e., cannot cite further causes)" (p. 10). The concept of leverage points has been applied in multiple fields, including public health (e.g., Glenn et al., 2020), mental health (e.g., van der Wal et al., 2021), and ecosystem health (e.g., Otero et al., 2022).

3.2. Degrowth strategy and policy

The present thesis adopts the definition of 'strategy' provided by Barlow et al. (2022) in *Degrowth & Strategy* – "a *thought construct* that details how one or several *actors* intend to bring about systemic change towards a desired end state" (p. 18, emphasis in original). In practice, a strategy serves as a "*flexible mental map* that links an analysis of the status quo to a vision of a desired end state" (Barlow et al., 2022, p. 18, emphasis in original). Therefore, a 'degrowth transition strategy' is understood as a concrete plan to elicit systemic change towards a future vision encompassing degrowth values (see Section 2.1 for an overview of the key tenets of degrowth). A degrowth transition strategy can be realised through the selection, planning, and implementation of a series of degrowth policies, each of which is "a course or principle of action adopted or proposed by an organisation or individual aiming to achieve the objectives of degrowth" (Parrique, 2019, p. 485). Such a broad definition of 'degrowth policy' allows for a diversity of actors to engage in policymaking, which supports the local, bottom-up approach to policymaking promoted by many degrowth advocates (Cosme et al., 2017).

4. Methods

This chapter presents the methods used to answer each of the research sub-questions presented in Section 1.4. In summary, the author used expert interviews and an expert workshop to develop a CLD representing the dominant feedback loops in the European aviation system (sub-question 1). Subsequently, the author identified variables representing leverage points for degrowth of European aviation based on a qualitative analysis of the feedback loops (sub-question 2). Figure 2 illustrates how the theoretical concepts (Chapter 3) and methods (Chapter 4) link to the main research question and sub-questions (Chapter 1).

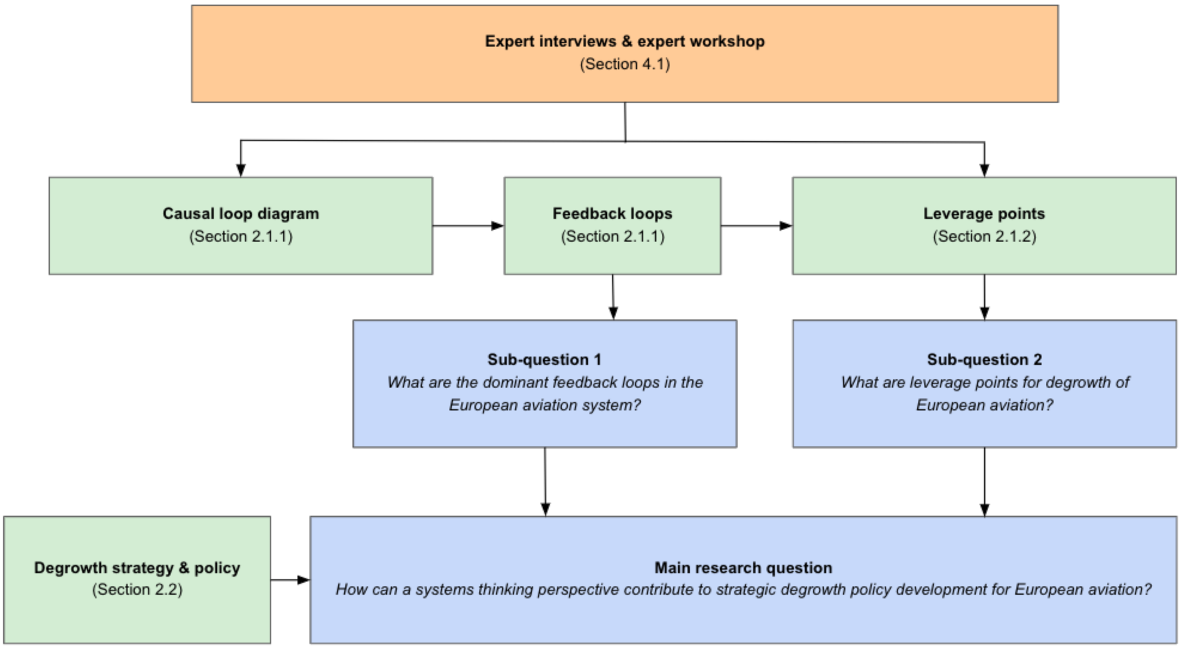

Figure 2. Analytical research framework illustrating the intersection of the research questions (Chapter 1), theoretical concepts (Chapter 3) and methods (Chapter 4). The combination of the expert interviews and expert workshop yielded a CLD illustrating the dominant feedback loops in the European aviation system (sub-question 1). Based on these feedback loops, as well as input from the expert interviews and workshop, the author identified leverage points for degrowth within the European aviation system (sub-question 2). Finally, the author linked the outcomes of the two research sub-questions to strategic degrowth policy development for European aviation, addressing the main research question.

4.1. Causal loop diagram

In order to address the first research sub-question, the author conducted (1) interviews with experts on (degrowth of) aviation and (2) a participatory systems mapping workshop with degrowth and aviation experts.

4.1.1. Expert interviews

The author conducted 25 semi-structured expert interviews. Particular care was taken to include a diversity of perspectives within the pool of interview participants in order to ensure the validity of the research. Therefore, interview participants included grassroots campaigners for degrowth of aviation, academic researchers, NGO representatives, and European airport and airline representatives.

In line with the General Data Protection Regulation, informed consent was obtained for every interview (Appendix A). As some interview participants requested for their names and organisations to remain anonymous, all interviews were anonymised to maintain consistency. A full, anonymised list of interview participants is presented in Appendix B. Interviews were recorded and transcribed using transcription software. Anonymised transcripts are available upon request.

The main aim of the interviews was to develop a comprehensive, nuanced overview of the variables and causal relationships at play within the European aviation system. Moreover, interview participants were asked to reflect on a degrowth pathway for European aviation, and participants who aligned themselves with a degrowth vision for the sector were asked to identify and discuss key degrowth policy measures.

The interview data were used as input for (1) the CLD developed during the participatory systems mapping workshop (Section 4.1.2) and (2) the identification of leverage points (Section 4.2). In order to adhere to the research questions, the results chapter (Chapter 5) only refers to the interviews that are relevant to understanding the feedback loops in the CLD and the subsequent selection of leverage points. Therefore, not all the interviews that were conducted are referenced in the results.

4.1.2. Expert workshop: Participatory systems mapping

'Participatory systems mapping' refers to a methodology where participants collectively develop a CLD on a given issue through a process of structured deliberation (Videira et al., 2014; Király et al., 2016). Participatory systems mapping has been used in previous research on degrowth and offers a compelling approach to grappling with degrowth policy questions (Videira et al., 2014; Király et al., 2016).

This methodology falls into the category of 'post-normal science,' which derives from the argument that complex socio-ecological issues with high system uncertainty and decision stakes, such as climate change, cannot effectively be addressed through conventional scientific means and tools (Funtowicz and Ravetz, 1993). Post-normal science places a large emphasis on participatory methods involving the 'extended peer community' (i.e., the involvement of a diversity of stakeholders beyond academia; Funtowicz and Ravetz, 1993), which facilitate knowledge-sharing and transdisciplinarity, invoke harmony through deliberation, and simulate real-world policy implementation processes (Kerkhof and Wieczorek, 2005; Foxon et al., 2009; Király et al., 2016).

The expert workshop took place at Utrecht University, the Netherlands, in September of 2023 and was attended by seven participants. The allocated time for the workshop was 3.5 hours. The aim of the workshop was to develop a CLD illustrating the feedback loops in the European aviation system, which explain the growth in European aviation activity. Workshop participants included degrowth researchers, aviation experts, and a night train company representative. The workshop participants were anonymised in order to maintain privacy. The full workshop was recorded, with prior consent obtained from the participants.

In advance of the workshop, participants were asked to familiarise themselves with the degrowth discourse on aviation; in particular, they were asked to skim the *Degrowth of Aviation* report by Stay Grounded (2019). The workshop started with participant introductions and a presentation summarising the degrowth argument for aviation, outlining the aims of the research, and providing instructions for the workshop. Subsequently, the author presented the participants with a preliminary set of system variables derived from the expert interviews (Section 4.1.1). The author informed the workshop participants that these variables should be considered a starting point for the CLD; therefore, not all had to be used, and more could be added as needed.

The allocated time for the CLD mapping exercise was 1.5 hours. A large sheet of paper was used as a canvas for the CLD. To promote equal engagement among the workshop participants, the preliminary variables were written on post-it notes and distributed among the participants. Blank post-it notes were available for additional variables. Drawing from the participatory methodology employed by Videira et al. (2014), the author first asked the participants to identify the variable(s) representing European aviation activity (i.e., 'problem variables'), which were placed in the centre of the large sheet of paper. Consequently, the participants added post-it notes with variables illustrating 'causes' and 'effects' and drew arrows representing causal relationships between these variables. For each relationship, participants indicated whether it was positive (i.e., changing in the same direction) or negative (i.e., changing in the opposite direction; Videira et al., 2014). The participants were encouraged to deliberate on these relationships and only add them to the map after reaching consensus. Moreover, participants were asked to focus on the most salient variables and relationships in order to maximise the map's clarity. The mapping exercise was followed by a discussion of the degrowth policy implications of the CLD. Throughout the workshop, the author maintained a primarily facilitative role, providing minimal content contributions to the workshop outcomes.

Following the workshop, the author developed a digital version of the system map using Kumu (https://kumu.io/), an online system mapping software. Moreover, the author analysed the workshop recording and noted key discussion points pertaining to the causal relationships included in the CLD. Subsequently, the author made the following (minor) revisions to the CLD: (1) adding relationships addressed in the recording but not reflected in the map (likely caused by oversight due to time constraints), (2) increasing the precision of variable names (based on how they were interpreted and utilised in the workshop discussion), and (3) merging redundant variables (i.e., those illustrating the same concept or idea) under one variable name.

The author shared the finalised CLD with the workshop participants with an invitation to comment. None of the participants had any feedback regarding the finalised CLD; therefore, the author proceeded with this version. In the results (Section 5.1), the author presents the variables and causal relationships that compose the main feedback loops (i.e., those including the problem variables) yielded by the CLD, as they help understand overall system behaviour and, therefore, are crucial for identifying leverage points. Additional feedback loops are presented in Appendix C.

4.2. Leverage points

Based on the feedback loops in the CLD, the author identified leverage points for degrowth of European aviation. Currently, there is not one standard way of qualitatively identifying leverage points based on a CLD (Crielaard et al., 2023); therefore, drawing on the theory presented in Section 3.1, the author developed the following criteria:

(1) **Recurrence throughout the feedback loops:** Variables that are part of multiple feedback loops have effects on multiple parts of the system and, therefore, play a key role in explaining system behaviour. Consequently, interventions that target these variables have significant system change potential and, therefore, constitute potential leverage points.

(2) **Accessibility of the intervention point:** Some recurring variables may be difficult — if not impossible — to target directly due to the nature of the variable and potential socio-political and physical barriers to intervention. Therefore, in addition to having high system change potential, intervening on a variable must be feasible in order for the variable to be classified as a leverage point.

The author justified the selection of the leverage points based on an analysis of the feedback loops, references to the theory on leverage points (Section 3.1.2), as well as information obtained from the workshop discussion and expert interviews.

5. Results

This chapter presents the main findings of the research, addressing the research sub-questions put forth in Chapter 1. First, the author presents the CLD developed during the expert workshop illustrating the feedback loops present within the European aviation system. Next, the author identifies and discusses leverage points for degrowth of European aviation.

5.1. Feedback loops

The CLD (Figure 3) includes 22 feedback loops in total. The workshop participants identified two problem variables: (1) total distance flown (represented through passenger kilometres) and (2) the total number of flights. This distinction was made to reflect different ways of measuring aviation activity, each with slightly different effects. Specifically, the climate impacts of aviation increase with flight distance, with long-haul flights contributing most to overall emissions from aviation (according to one workshop participant, the 20% longest flights contribute to 80% of aviation's climate impacts); alternatively, the total number of flights, regardless of distance, contributes to climate impacts as well as local effects, such as noise around airports.

In order to focus on the findings that directly influence the amount of aviation activity, this chapter focuses on the 15 feedback loops (six reinforcing and nine balancing feedback loops) that include one of the problem variables (Table 2). The remaining seven feedback loops are presented in Appendix C (Table C1). Table 1 defines the variables present in the feedback loops discussed in this chapter.

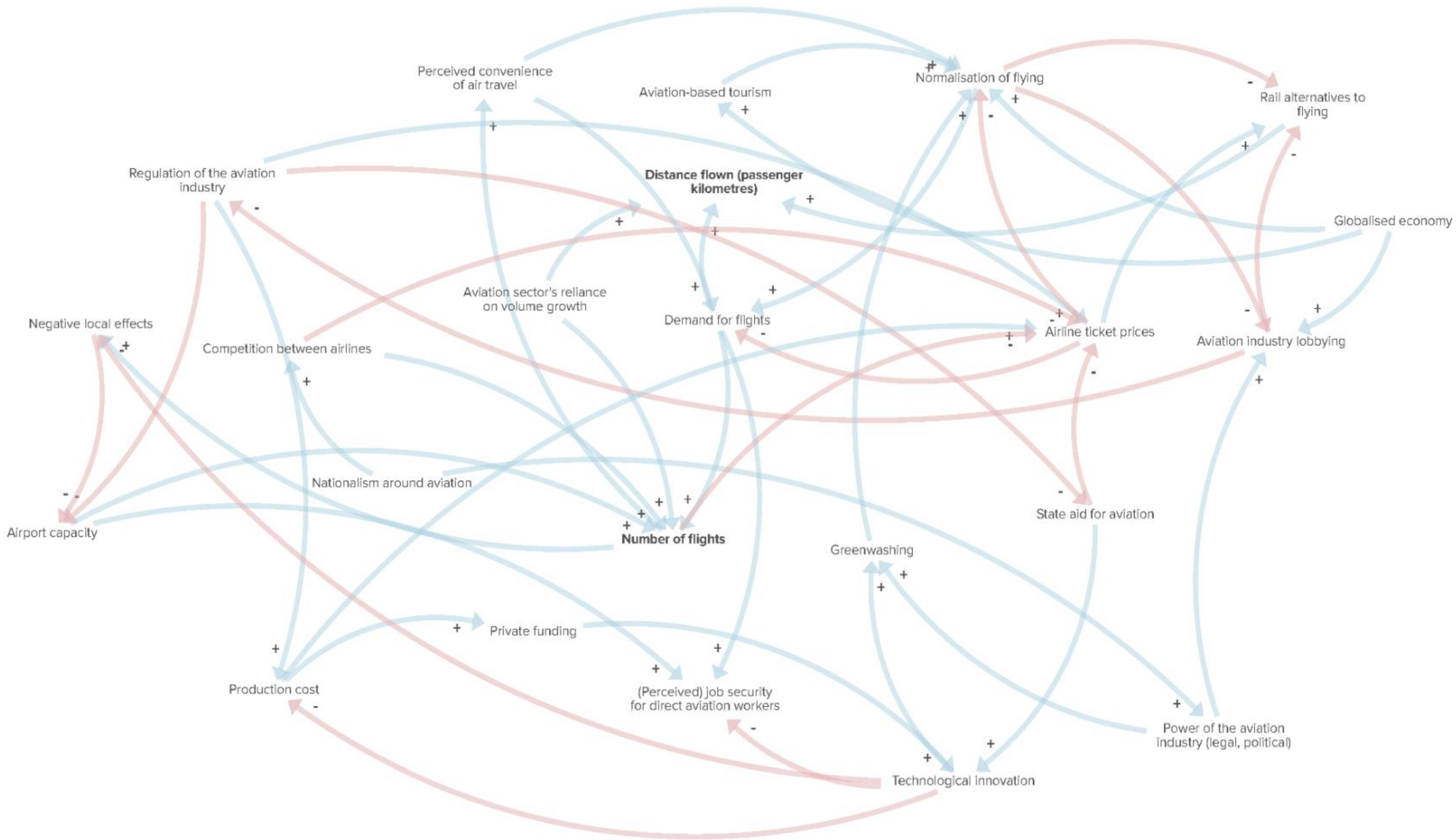

Figure 3. A CLD illustrating the feedback loops present in the European aviation system. A high-resolution, interactive version of the CLD can be accessed here. The problem variables are indicated in bold font. The blue arrows indicated positive (+) causal effects, while the red arrows indicate negative (-) causal effects. For details on how to interpret a CLD, please see Section 3.1.

Table 1. The system variables included in the feedback loops presented in Table 2, as they were defined and operationalised during the expert workshop.

Variable	**Definition**
Number of flights	The total number of flights within the European aviation system. This is an indicator of total aviation activity.
Perceived convenience of air travel	The perception of air travel as being more convenient than alternative travel options in terms of efficiency, comfort, and convenience.
Demand for flights	The quantity of flight tickets consumers are willing to purchase.
Airline ticket prices	The prices charged by airlines for flight tickets. This reflects the purchase price of flying, paid by the consumer.
Negative local effects	The detrimental effects (especially noise) of flights on the local residents and environment around airports.
Airport capacity	The number of flights that can be accommodated at airports within the European aviation system.
Normalisation of flying	The perception of flying as a 'need' or a 'right' - for private as well as business travel.
Aviation industry lobbying	The aviation industry's level of influence over policymaking, especially addressing the industry's climate impacts.
Regulation of the aviation industry	The level of stringency of regulations externally imposed on the aviation industry, especially those addressing the sector's environmental impacts, based on policies enforced by national and international regulatory bodies.
Production costs	The expenses incurred by the aviation industry (e.g., fuel and labour costs for airlines).
State aid for aviation	Financial investment into the aviation industry by government bodies (e.g., subsidies).
Technological innovation	The development of more advanced technologies within the aviation industry that contribute to alleviating the sector's environmental impacts (e.g., noise, climate).
Private funding	Private financial investment into the aviation industry (e.g., company shareholders).

Table 2. The 15 feedback loops (six reinforcing and nine balancing feedback loops) in the CLD (Figure 3) that include one of the problem variables (bold).

Reinforcing feedback loops	
Label	**Variables**
R1	**Number of flights** → (+) Perceived convenience of air travel → (+) Demand for flights → (+) **Number of flights**
R2	**Number of flights** → (-) Airline ticket prices → (-) Demand for flights → (+) **Number of flights**
R3	**Number of flights** → (+) Perceived convenience of air travel → (+) Normalisation of flying → (+) Demand for flights → (+) **Number of flights**
R4	**Number of flights** → (-) Airline ticket prices → (-) Normalisation of flying → (+) Demand for flights → (+) **Number of flights**
R5	**Number of flights** → (+) Perceived convenience of air travel → (+) Normalisation of flying → (-) Aviation industry lobbying → (-) Regulation of the aviation industry → (+) Production costs → (+) Private funding → (+) Technological innovation → (-) Negative local effects → (-) Airport capacity → (+) **Number of flights**
R6	**Number of flights** → (-) Airline ticket prices → (-) Normalisation of flying → (-) Aviation industry lobbying → (-) Regulation of the aviation industry → (+) Production costs → (+) Private funding → (+) Technological innovation → (-) Negative local effects → (-) Airport capacity → (+) **Number of flights**

Balancing feedback loops	
Label	**Variables**
B1	**Number of flights** → (+) Negative local effects → (-) Airport capacity → (+) **Number of flights**
B2	**Number of flights** → (+) Perceived convenience of air travel → (+) Normalisation of flying → (-) Aviation industry lobbying → (-) Regulation of the aviation industry → (-) Airport capacity → (+) **Number of flights**
B3	**Number of flights** → (-) Airline ticket prices → (-) Normalisation of flying → (-) Aviation industry lobbying → (-) Regulation of the aviation industry → (-) Airport capacity → (+) **Number of flights**
B4	**Number of flights** → (+) Perceived convenience of air travel → (+) Normalisation of flying → (-) Aviation industry lobbying → (-) Regulation of the aviation industry → (+) Airline ticket prices → (-) Demand for flights → (+) **Number of flights**
B5	**Number of flights** → (+) Perceived convenience of air travel → (+) Normalisation of flying → (-) Aviation industry lobbying → (-) Regulation of the aviation industry → (+) Production costs → (+) Airline ticket prices → (-) Demand for flights → (+) **Number of flights**
B6	**Number of flights** → (+) Perceived convenience of air travel → (+) Normalisation of flying → (-) Aviation industry lobbying → (-) Regulation of the aviation industry → (-) State aid for aviation → (-) Airline ticket prices → (-) Demand for flights → (+) **Number of flights**
B7	**Number of flights** → (+) Perceived convenience of air travel → (+) Normalisation of flying → (-) Aviation industry lobbying → (-) Regulation of the aviation industry → (-) State aid for aviation → (+) Technological innovation → (-) Negative local effects → (-) Airport capacity → (+) **Number of flights**

B8	**Number of flights** → (-) Airline ticket prices → (-) Normalisation of flying → (-) Aviation industry lobbying → (-) Regulation of the aviation industry → (-) State aid for aviation → (+) Technological innovation → (-) Negative local effects → (-) Airport capacity → (+) **Number of flights**
B9	**Number of flights** → (+) Perceived convenience of air travel → (+) Normalisation of flying → (-) Aviation industry lobbying → (-) Regulation of the aviation industry → (-) State aid for aviation → (+) Technological innovation → (-) Production costs → (+) Airline ticket prices → (-) Demand for flights → (+) **Number of flights**

Note: Each feedback loop is labelled with 'R' (reinforcing) or 'B' (balancing). A positive causal effect is indicated by '→ (+)', while a negative causal effect is indicated by '→ (-)'. For more information on how to interpret feedback loops, please see Section 3.1.1 (Figure 1).

Of the two problem variables introduced above, only the 'number of flights' variable appears in the feedback loops, as the 'total distance flown' variable was only identified by the participants as an effect, not a cause of any other variables. This is likely due to the time constraints of the workshop, which prevented participants from having the time to check and refine the CLD. Please see Section 7.2 for a discussion of the methodological limitations of the research. Nonetheless, as discussed earlier, the number of flights is an indicator of the climate impacts of aviation; therefore, focusing on this problem variable alone still highlights the main issue addressed by the present study (see Section 1.3 for more details).

The following text elaborates on the causal relationships at play within the feedback loops presented in Table 2. As there is overlap in the causal links constituting the reinforcing and balancing feedback loops, the author first focuses on the relationships present in the reinforcing feedback loops (R1-6), which represent the processes driving the growth in the number of flights. Next, the author addresses the remaining causal relationships at play within the balancing feedback loops (B1-9), which work to maintain system stability (i.e., prevent significant change in the number of flights). It should be noted that justifications for the causal relationships were mainly derived from the workshop discussion and are supported by information obtained from the expert interviews. References to the interviews (Appendix B) are provided in brackets. Statements without references were derived from the expert workshop.

5.1.1. Reinforcing feedback loops

The first four reinforcing feedback loops (R1-4; Table 2) share the positive causal link from 'demand for flights' to 'number of flights'. During the workshop, this link was established to represent the direct effect of demand for aviation on the supply of flights, illustrating the crucial role of consumer demand in driving aviation activity. The reinforcing feedback loops present three direct causes of demand: 'perceived convenience of air travel' (R1), 'airline ticket prices' (R2), and 'normalisation of flying' (R3-4).

The perceived convenience of air travel was found to directly increase demand for flying by warranting the decision to fly rather than taking alternative (potentially less convenient) modes of transportation, such as train travel. Alternatively, as illustrated in R3, the perceived convenience of flying was found to indirectly influence demand for flying via the ‘normalisation of flying’ variable, as the convenience of a travel option directly influences its perceived normality and necessity. An interviewee illustrated this by reflecting on her personal experience travelling by train between Hungary and Belgium, explaining how the inconvenience of train travel makes a long-distance train journey seem absurd, even for an advocate for degrowth of aviation:

> It's a pain in the neck not to fly if you actually want to get to places. [...] I did want to be in Brussels, and I'm really happy I made it to Brussels. But [...] changing three times and being late and whatever is not something that I truly enjoyed. I thought I was being crazy. (Interview #2).

Consequently, the perceived convenience of air travel (especially relative to train travel) was found to increase the normalisation of flying, leading to an increase in demand for flying and, consequently, the number of flights (R3-4).

Furthermore, the negative link between airline ticket prices and demand for flights was included to illustrate how declining airline ticket prices directly increase demand for flying by making aviation accessible to a larger socio-economic demographic (R2). Alternatively, airline ticket prices were also found to indirectly influence demand for flying via the normalisation of flying (R4). This is based on the argument that, as flying has become cheaper, the cultural norms around aviation have shifted from flying being perceived as a luxury towards something “necessary and [...] desirable” (Interview #10). One element of this is the normalisation of recreational flying. For example, according to a Netherlands-based climate journalist, it used to be standard for working Dutch people to travel by car to southern Europe during their holiday for a “guarantee of sunshine”; however, after flying became cheaper, it became normal to take the plane for one’s holiday, for example to Turkey (Interview #1).

Another aspect of the negative causal relationship between airline ticket prices and the normalisation of flying (R4, R6) is the social ‘lock-in’ of aviation (i.e., people coming to depend on the availability of affordable aviation), in part resulting from increasingly dispersed social networks (Interview #19). According to a transport researcher, the availability of cheap air travel has created the expectation that migration does not necessitate an interruption in contact with one’s social network, as it did several decades ago; rather, “now people […] have an expectation that […] I will live 5,000 kilometres away but still be able to be back every couple of weeks if I want to” (Interview #19). Thus, people structure their lives based on the assumption of the continued availability of cheap air travel, perpetuating its perceived necessity. As a result of this social lock-in effect, people whose social networks are dispersed across large spatial distances tend to fly more than those with friends and family in proximity (Interview #19).

The 'number of flights' variable was included as a cause of the 'perceived convenience of air travel' (R1, R3, R5) and 'airline ticket prices' (R2, R4, R6) variables. The former link was included by the workshop participants to show that a greater number of flights has a positive impact on the perceived convenience of air travel by creating a greater number of flight options (and, therefore, greater travel flexibility). The effect of the number of flights on airline ticket prices was included to reflect the economic principle that a greater supply of a product lowers the purchase price of that product.

Two of the reinforcing feedback loops (R5-6) include negative causal links between the 'normalisation of flying' and 'aviation industry lobbying' variables, and the 'aviation industry lobbying' and 'regulation of the aviation industry' variables. During the workshop, the first of these links was established to illustrate a predicted increase in aviation industry lobbying efforts to combat the de-normalisation of flying (i.e., a reduction in the normalisation of flying). To substantiate this claim, one workshop participant referenced the increase in aviation industry lobbying in response to the 'flight shame' (*flygskam*) movement, which was part of a broader movement in Sweden drawing attention to the environmental impacts of aviation and encouraging individuals to fly less (Interview #10).

Aviation industry lobbying was identified as having a negative causal effect on the regulation of the aviation industry; in other words, a greater level of industry lobbying was found to lead to less stringent external regulation of the industry. According to an aviation analyst at an organisation investigating corporate climate policy influence, the aviation industry successfully lobbies for minimal regulation:

> Aviation is one of the least regulated industries, particularly in transport. Yet it is [...] one of the biggest emitters and will continue to be [...] especially if they grow as they plan to. So, we can infer that they are very successful in their lobbying. (Interview #13).

For example, the fact that the EU ETS does not apply to international flights can largely be attributed to aviation industry lobbying efforts (Interview #13).

The regulation of the aviation industry was found to have a positive causal effect on production costs (R5-6). For example, regulations mandating the use of SAF would increase fuel costs for airlines, thereby increasing production costs. This results in the need for increased (private) funding to support the higher production costs (R5-6). Private funding was also found to support technological innovation, which can in turn counteract negative local effects of aviation activity (R5-6); for example, aircraft noise pollution can be mitigated through the development of quieter aircraft. Finally, the negative local effects of aviation were established as having a negative causal effect on airport capacity as noise pollution has been found to limit airport expansion; therefore, if negative local effects would be mitigated through technological innovation, this could allow for airport expansion, which would lead to greater airport capacity and, therefore, more flights (R5-6).

While the reinforcing feedback loops illustrate the processes that drive the growth in aviation activity under current conditions, they also have the potential to have the opposite effect and shift the system onto a degrowth trajectory. For example, according to R3, the de-normalisation of flying would elicit a reduction in demand for flights and, subsequently, the number of flights, which would in turn reduce the perceived convenience of air travel, which would lead to a further de-normalisation of flying. Therefore, these reinforcing feedback loops are crucial to consider in strategic degrowth policy discussions for European aviation.

5.1.2. Balancing feedback loops

While several of the causal relationships described in the previous section are also present in the balancing feedback loops (see Table 2), the present section focuses on the relationships that have not yet been discussed. Notably, all but one (B1) of the balancing feedback loops include the negative causal links between the 'normalisation of flying' and 'aviation industry lobbying' variables and the 'aviation industry lobbying' and 'regulation of the aviation industry' variables (discussed above), indicating the importance of these relationship to the stabilising processes at play within the system.

In addition to the effect of the regulation of the aviation industry on production costs, which is discussed in the previous section, the 'regulation' variable was established as having direct causal effects on airport capacity (B2-3), airline ticket prices (B4), and state aid (B6-9). The negative causal effect of regulation on airport capacity can be illustrated through the Dutch government's implementation of a flight cap at Schiphol Airport (despite significant industry pushback) in 2023: following the enforcement of more stringent regulation (i.e., the flight cap), airport capacity decreased, leading to a reduction in the number of flight movements at Schiphol (Interviews #13 and #22).

Furthermore, the regulation of the aviation industry was found to have both a direct positive causal effect on airline ticket prices (B4) and an indirect positive causal effects effect via an increase in production costs (B5) and a reduction in state aid (B6). The direct effect of regulation on airline ticket prices refers to regulation measures directly targeting ticket prices, such as value added tax (VAT) on airline tickets or a passenger ticket tax. The indirect effect via production costs refers to measures which raise production costs (such as a kerosene tax, which leads to increased fuel costs), resulting in higher airline ticket prices, as the increased costs would be shifted to consumers.

Moreover, the indirect effect of regulation on airline ticket prices via state aid was established to illustrate how increasingly stringent regulation of the aviation industry would lead to less public funding for airlines through subsidies and state aid, which would consequently increases airline ticket prices, as the sale of airline tickets would constitute a larger share of airlines' revenue. Indeed, it is important not to underestimate the importance of state funding in aviation; according to a climate journalist, state funding was largely responsible for airline company KLM's (of the Air France-KLM Group) historically leading role in the international aviation industry (Interview #1). State aid was also found to fund technological innovation in the aviation industry (B7-9), and, subsequently, technological innovation was found to decrease production costs through the development of more efficient technologies (e.g., more efficient engines, which consume less fuel and, therefore, yield lower fuel costs).

The balancing feedback loops discussed here maintain system stability; therefore, under the current growth trajectory for European aviation, they help mitigate some of the increase in the number of flights arising from the reinforcing feedback loops. However, these balancing feedback loops can also hinder efforts to degrow aviation by 'correcting' reinforcing processes that can potentially drive degrowth of the sector. For example, according to R3-6, the de-normalisation of flying would initiate a reinforcing process that would contribute to a decreasing number of flights. However, according to B2-9, any change in the 'normalisation of flying' variable would be stabilised by the balancing feedback loops (B2-9), thereby preventing a significant change in the number of flights. Therefore, it is important to consider the reinforcing and balancing processes together when strategising for degrowth of aviation.

5.2. Leverage points

Based on the criteria presented in Section 4.2, the author proposes the following leverage points for degrowth of European aviation: (1) aviation industry lobbying and (2) airline ticket prices. Each of these leverage points is discussed below.

5.2.1. Aviation industry lobbying

The 'aviation industry lobbying' variable is present in two of the reinforcing feedback loops (R5-6) and all but one of the balancing feedback loops (B1; Table 2), illustrating its significance to the behaviour of the system. In each of these feedback loops, it appears as the cause of the 'regulation of the aviation industry' variable and the effect of the 'normalisation of flying' variable. Compared to these variables, the 'lobbying' variable was deemed the best intervention point due to its relatively accessibility. The normalisation of flying is a paradigm-level intervention point according to Meadows' (1999) ranking; therefore, degrowth measures targeting this variable can have profound systemic effects, but they also face significant barriers, especially due to the 'social lock-in' processes discussed earlier. Furthermore, directly targeting the 'regulation of the aviation industry' variable would require an intervention that would demand for regulatory bodies to enforce stringent, degrowth-aligned measures on the aviation industry. According to a representative of a grassroots organisation advocating for degrowth of aviation, this is unlikely to happen under the current aviation policy landscape due to regulatory bodies' (especially ICAO's) invested interest in the growth of the aviation industry (Interview #24). Consequently, this interview participant argued that effectively aligning the regulation of the aviation industry with degrowth objectives would require reducing ICAO's regulatory power and establishing a new, independent regulatory body whose primary goal would be emissions reduction for the industry. However, such an intervention would face significant socio-political pushback and, therefore, makes the 'regulation of the aviation industry' variable a relatively inaccessible intervention point.

On the other hand, the present research suggests that reducing aviation industry lobbying is both an intervention that is both powerful (due to its recurrence throughout the feedback loops) and accessible. While the lobbying power of the aviation industry is strong, one interview participant proposed measures targeting this variable that are both effective and relatively feasible (Interview #13). These measures aim to increase lobbying transparency and hold the aviation industry accountable for its negative impact on climate policy. For example, the interview participant proposed the introduction of a new EU-level law that would increase the transparency of meeting data between aviation industry representatives and policymakers.

Moreover, as the 'lobbying' variable has a direct negative causal effect on the regulation of the aviation industry, efforts to reduce the lobbying power of the industry can increase the stringency of aviation industry regulation and, thus, reduce barriers to implementing measures targeting the regulation of the aviation industry (e.g., establishing a new regulatory body, as discussed above).

5.2.2. *Airline ticket prices*

The 'airline ticket prices' variable plays an important role in the feedback loops, as it has a direct causal effect on the 'demand for flights' and 'normalisation of flying' variables, which appear in all but one of the feedback loops (B1; Table 2). As discussed in Section 5.2.1, the normalisation of flying has significant system change potential but faces substantial socio-political barriers to intervention. Moreover, the demand for flights by nature cannot be targeted directly and can only be addressed through other variables (i.e., those which are the causes of demand). Therefore, targeting airline ticket prices – a mutual cause of these variables – can have significant systemic effects.

While the 'perceived convenience of air travel' variable was also established a mutual cause of the 'demand' and 'normalisation' variables, airline ticket prices constitute the more accessible intervention point as, similar to the demand for flights, the perceived convenience of air travel is determined by other factors, particularly the number of flights, as illustrated in the CLD. Airline ticket prices, however, can be targeted directly through various policy interventions, such as VAT on airline tickets and passenger ticket taxes, as mentioned in Section 5.1.2.

Airline ticket prices correspond to the 'constants, parameters, numbers' category in Meadows' (1999) ranking, which Meadows identifies as the least effective among her 12 categories of leverage points. “Diddling with the details,” she states, “99 percent of our attention goes to parameters, but there’s not a lot of leverage in them” (p. 6). However, Meadows acknowledges that numbers do constitute leverage points “when they go into ranges that kick off one of the items higher on this list” (p. 6). Therefore, in order to trigger a reduction in demand for flights, a de-normalisation of flying, and a subsequent systemic transformation towards degrowth, the change in airline ticket prices would need to be of a large enough magnitude to elicit significant behavioural change. As was pointed out by a workshop participant, a minor increase in airline ticket prices would do little to change behaviour but would also be relatively easy to implement, while a measure increasing airline ticket prices more drastically would elicit significant socio-political pushback. Therefore, the ideal intervention on this leverage point would be drastic enough to change consumer behaviour but still maintain socio-political acceptance.

A policy measure that potentially meets both of these criteria is a frequent flyer tax (FFT), which is a progressive tax on airline tickets (discussed during the workshop and in some interviews, e.g., Interview #23) that makes each subsequent flight taken by an individual within a given time period progressively more expensive. According to a representative of a grassroots organisation advocating for degrowth of aviation, a FFT can be both highly effective (especially if it is exponentially progressive, thereby deterring even the wealthiest flyers and business travellers) and evokes more public support than other progressive taxation measures because it explicitly targets frequent flyers (who contribute the most to the emissions from aviation), rather than, for example, someone who might fly once every few years to visit their family overseas (Interview #23). Therefore, interventions such as a FFT can elicit the transformative potential of an increase in airline ticket prices, potentially shifting the system onto a degrowth trajectory. However, it is important to note that the successful implementation of a FFT faces some practical difficulties (e.g., the collection and storage of individuals’ flight data), which are important to consider in the planning of this measure.

6. Conclusions

The present chapter explains how the findings presented in the previous chapter address the main research question of the thesis (Section 1.4):

How can a systems thinking perspective contribute to the strategic selection of degrowth policies for European aviation?

The feedback loops (Table 2) provide a tool for ex-ante (i.e., pre-implementation) evaluation of the systemic effects of potential degrowth policy interventions. Furthermore, the leverage points identified in Section 5.2 illustrate key policy intervention points, which are both accessible and effective at the systemic level. The following sections summarise the main findings of the research and illustrate how they contribute to strategic degrowth policy selection, which can in turn inform the development of effective degrowth transition strategies for European aviation.[1]

6.1. Feedback loops

The first sub-question guiding the research is the following: *What are the dominant feedback loops in the European aviation system?* Based on the CLD of the European aviation system developed during the expert workshop (Figure 3), the author identified 15 feedback loops directly affecting the total number of flights within European aviation (Table 2). These feedback loops represent key processes explaining the dynamics of the European aviation system; therefore, they can be leveraged to facilitate a degrowth transition. Policymakers, researchers, and grassroots campaigners can use the CLD to evaluate how a degrowth policy targeting a particular variable would alter the behaviour of the system as a whole (see Table 5 of Videira et al., 2014, for an example), contributing to the strategic selection and implementation of degrowth policies. Therefore, the research directly addresses the research gap presented in Section 1.2 by providing an analytical tool to link degrowth policies to the issues they are aiming to address, thereby contribution to the development of degrowth transition strategies.

6.2. Leverage points

The second sub-question guiding the research is the following: *What are leverage points for degrowth of European aviation?* Drawing on the feedback loops (Table 2), input from the expert interviews and workshop, and the theoretical frameworks for identifying leverage points (Section 3.1.2), the author identified the following leverage points for degrowth of European

[1] Due to the methodological limitations of the present study (discussed in Section 7.2), the author advises for the findings and conclusions of the present study to be taken up carefully and validated with further research, as discussed in Section 7.3.

aviation: (1) aviation industry lobbying and (2) airline ticket prices. The author argues that targeting these variables through degrowth policy interventions is both feasible and can have profound systemic effects (see Section 4.2); therefore, it may be wise for policymakers to prioritise degrowth policies targeting these variables. Additionally, by addressing these variables, it may become more feasible to implement policies targeting other variables in the system. For example, as mentioned in Section 5.2.1, intervening on the 'normalisation of flying' variable has the potential to significantly transform the system due to this variable's recurrence throughout the feedback loops and position within the top categories of Meadows' (1999) ranking; however, this variable faces major socio-political barriers to intervention, which is why it was not selected as a leverage point. As this variable is directly affected by airline ticket prices (Table 2), a policy that increases airline ticket prices would already contribute to the 'de-normalisation' of flying and, consequently, potentially remove some barriers to intervening directly on the 'normalisation' variable. In other words, policies intervening on the leverage points can 'enable' the implementation of policies targeting other variables in the system, especially those 'downstream' of the leverage points (i.e., constituting 'effects' of the leverage points). In this way, the feedback loops can reveal potential interactions between degrowth policies and, subsequently, inform their sequential planning, addressing important gaps in the academic degrowth policy literature (Section 2.2).

In conclusion, the present research has provided an analytical foundation for the strategic selection of degrowth policies for European aviation, thereby contributing to the development of degrowth transition strategies. The following chapter explores how this research fits within the broader context of degrowth policy literature and provides recommendations for future research.

7. Discussion

7.1. Scientific contribution

By using a systems thinking approach to inform degrowth policy development for European aviation, the present research provides several contributions to the scientific literature. First, to the author's knowledge, this is the first academic study exploring the topic of degrowth of aviation from a systems thinking perspective. Therefore, the present research complements existing work aiming to inform degrowth policymaking for aviation (e.g., Stay Grounded 2019; Katz-Rosene and Ambe-Uva, 2023). For example, the degrowth policies proposed by Stay Grounded (2019) can be directly evaluated using the CLD developed in the present research to assess their system-level effects. Moreover, the Stay Grounded campaign may consider focusing their efforts on policies targeting the leverage points identified in the present research due to these variables' high system change potential and relative accessibility. Additionally, the degrowth-centred multilateral environmental agreement proposed by Katz-Rosene and Ambe-Uva (2023) targets the 'regulation of the aviation industry' variable in the CLD (Figure 3); thus, the present research can help contextualise the regulatory intervention proposed by the authors within the broader European aviation system, illustrating how the proposed environmental agreement might affect the systemic feedback loops and, ultimately, the total amount of aviation activity. Overall, the present research can be used to draw connections between degrowth-oriented studies and efforts addressing different parts of the European aviation system, thereby laying the foundation for a more coherent, coordinated movement calling for degrowth of European aviation.

The present research also addresses some of the limitations of degrowth policy research identified by Fitzpatrick et al. (2022). Particularly, the present research addresses the problem of 'policy dropping' by providing an analytical foundation for linking degrowth policies to key feedback loops within a particular system. Moreover, by identifying leverage points within the system, the present research justifies prioritising certain policies (i.e., those targeting the leverage points) over others, rather than selecting policies simply due to their existing popularity. Additionally, as mentioned in Section 6.2, degrowth policies targeting the leverage points can 'enable' the implementation of policies targeting variables with greater barriers to intervention. This illustrates how systems thinking tools can be used to identify 'unconscious' or 'enabling' policies, which Fitzpatrick et al. (2022) identified as important to developing effective degrowth transition strategies.

This thesis also contributes to the body of academic literature applying systems thinking to degrowth policy discourse, such as Videira et al. (2014), Đula et al. (2019), and Parrique (2019). One study that takes a similar approach as the present study, albeit applied to a different sector, is that by Chakori et al. (2021). In both that study and the present study, a CLD was developed to identify the main systemic drivers of a particular issue (the use of single-use packaging and the growth of aviation activity, respectively) and, subsequently, leverage points were identified to shift the system in question onto a more sustainable trajectory. One key difference is that, in the present case, the necessity of degrowth of aviation was the fundamental premise of the study; however, in the study on food packaging, the importance of an economic degrowth framework emerged as one of the findings. Both of these studies offer a general framework for developing degrowth policy recommendations for a particular sector using a systems thinking approach, which can be applied to other sectors in future research (see Section 7.3). Notably, the present study presents a set of criteria for identifying leverage points based on a CLD (Section 4.2), which can be replicated and refined in future research.

7.2. Methodological limitations

Due to the resource and time constraints of the present research, there are several limitations that are important to note, particularly pertaining to the participatory systems mapping workshop. First, the workshop included seven participants, which is a relatively low number compared to other studies employing participatory systems mapping in a degrowth context; particularly, Videira et al. (2014) and Király et al. (2016) included 15 and nine expert participants, respectively. Despite their low number, the workshop participants in the present study represented a diversity of perspectives and backgrounds. Moreover, the variables used to build the CLD during the workshop were based on 25 expert interviews conducted prior to the workshop, which reduces some of the potential validity issues arising from the relatively small number of workshop participants. Additionally, having a small group of participants contributed to the participatory element of the workshop, as each participant had more opportunities to contribute to the discussion, and it was easier to ensure equal participation.

Another limitation of the expert workshop was the limited time that was available for developing the CLD. As a result, there was little capacity to refine the CLD to ensure its clarity and accuracy. However, as described in Section 4.1.2, after the workshop, the author shared the digitalised version of the CLD with the workshop participants with an invitation to comment, allowing the participants to point out any significant errors or omissions. In order to increase the validity of the findings, it would be necessary to replicate the workshop with different groups of aviation experts and compare the results. The present research offers a structured participatory systems mapping methodology (Section 4.1.2) that can be replicated in further research on this subject (see Section 7.3). Additionally, due to the limited time available for the workshop, the CLD includes only the basic components of a CLD (i.e., variables and causal links) and does not include additional elements, such as delays, which can help create a more detailed and accurate illustration of a system (Kim, 1999).

Finally, while the selection of leverage points was based on explicit criteria (Section 4.2), it was still subject to a subjective interpretation of the research outcomes. Therefore, the selection of the leverage points would have been sounder if it had been validated by experts, such as the interview and/or workshop participants. Due to time constraints, this step was not taken in the present research; however, it would be important to consider in future research adopting a similar methodology.

7.3. Recommendations for future research

The author recommends three avenues for future research: (1) replicating the methodology of the present study in order to increase the validity of the outcomes, (2) applying the methodology of the present study to other case studies (i.e., other sectors and regions), and (3) building on the findings of the present study to provide a deeper contribution to degrowth policy for European aviation by, for example, assessing potential interactions between specific degrowth policies.

First, it would be important to replicate the present research, perhaps with slight modifications, in order to ensure the accuracy and soundness of the results, which is especially important if they are to be used to influence policymaking. It would be interesting to compare the outcomes of the various iterations of the research and note and investigate any significant differences. One potential adaptation of the methodology would be conducting the participatory systems mapping workshop without providing the participants with a preliminary set of variables and, rather, asking the participants to come up with the variables themselves. This was pointed out by one of the workshop participants in the present study as a potentially valuable alternative approach, as it would create fewer constraints and, consequently, allow the participants to think 'outside the box'.

Furthermore, as discussed in Section 2.2, there are few studies to date applying systems thinking methodologies to the exploration of degrowth of specific sectors. Therefore, another potential avenue for future research would be to replicate the methodology of the present study in relation to other sectors, especially those with high projected growth rates and limited 'green growth' solutions. Aside from air travel, such difficult-to-decarbonise sectors include long-distance freight transport, highly reliable electricity, and steel and cement manufacturing due to the combination of rapidly increasing demand for these services, long lead times for technology development, and long lifetimes of energy infrastructure (Davis et al., 2018). Additionally, as the present study focuses on Europe, it would be valuable to replicate the methodology for the aviation sectors in other regions, such as the US — where a 2017 baseline scenario projects the air transport market to grow by 62% by 2037 (IATA, n.d.) — or based on a global perspective. Moreover, since the present study excludes private, freight, and military aviation, it would be interesting to include these branches of aviation in future research.

Finally, this research can be used as a foundation for future studies to make further contributions to degrowth policy for European aviation, which were outside of the scope of the study. For example, Videira et al. (2014) complemented their systems thinking analysis (based on CLDs and leverage points) with an assessment of interactions between a set of emblematic degrowth policy proposals, yielding a more thorough and useful contribution to academic degrowth policy discourse than the systems thinking analysis alone. Assessing interactions between degrowth policy proposals for European aviation would be a particularly useful avenue for future research, as considering policy interactions is key to the development of effective degrowth transition strategies (Fitzpatrick et al., 2022).

References

Barlow, N., Regen, L., Cadiou, N., Chertkovskaya, E., Hollweg, M., Plank, C., Schulken, M., & Wolf, V. (2022). *Degrowth & strategy: How to bring about social-ecological transformation*. MayFly. https://www.degrowthstrategy.org/

Basner, M., Clark, C., Hansell, A., Hileman, J. I., Janssen, S., Shepherd, K., & Sparrow, V. (2017). Aviation noise impacts: State of the science. *Noise & Health*, *19*(87), 41–50. https://doi.org/10.4103/nah.NAH_104_16

BSR. (2023). A credible future beyond growth. [J. Dugard, & G. Berruti (authors)]. https://www.bsr.org/en/blog/a-credible-future-beyond-growth#:~:text=In%202023%2C%20the%20conference%20hall,the%20European%20Parliament%2C%20Roberta%20Metsola

Chakori, S., Aziz, A. A., Smith, C., & Dargusch, P. (2021). Untangling the underlying drivers of the use of single-use food packaging. *Ecological Economics*, *185*, 107063. https://doi.org/10.1016/j.ecolecon.2021.107063

Chakori, S., Richards, R., Smith, C., Hudson, N. J., & Abdul Aziz, A. (2022). Taking a whole-of-system approach to food packaging reduction. *Journal of Cleaner Production*, *338*, 130632. https://doi.org/10.1016/j.jclepro.2022.130632

Cosme, I., Santos, R., & O'Neill, D. W. (2017). Assessing the degrowth discourse: A review and analysis of academic degrowth policy proposals. *Journal of Cleaner Production*, *149*, 321–334. https://doi.org/10.1016/j.jclepro.2017.02.016

Creutzig, F., Roy, J., Devine-Wright, P., Díaz-José, J., Geels, F.W., Grubler, A., Maïzi, N., Masanet, E., Mulugetta, Y., Onyige, C.D., Perkins, P.E., Sanches-Pereira, A., & Weber, E.U. (2022). Demand, services and social aspects of mitigation. In IPCC, 2022: *Climate change 2022: Mitigation of climate change*. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, & J. Malley (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. https://doi.org/10.1017/9781009157926.007

Crielaard, L., Quax, R., Sawyer, A. D. M., Vasconcelos, V. V., Nicolaou, M., Stronks, K., & Sloot, P. M. A. (2023). Using network analysis to identify leverage points based on causal loop diagrams leads to false inference. *Scientific Reports*, *13*(1), Article 1. https://doi.org/10.1038/s41598-023-46531-z

Dahal, K., Brynolf, S., Xisto, C., Hansson, J., Grahn, M., Grönstedt, T., & Lehtveer, M. (2021). Techno-economic review of alternative fuels and propulsion systems for the aviation sector.

Renewable and Sustainable Energy Reviews, *151*, 111564. https://doi.org/10.1016/j.rser.2021.111564

Dale, G., Mathai, M., & Puppim de Oliveira, J. (2016). *Green growth: Ideology, political economy and the alternatives*. Zed Books and Aakar Books. https://www.researchgate.net/publication/341679443_Green_Growth_Ideology_Political_Economy_and_the_Alternatives

Darda, S., Papalas, T., & Zabaniotou, A. (2019). Biofuels journey in Europe: Currently the way to low carbon economy sustainability is still a challenge. *Journal of Cleaner Production*, *208*, 575–588. https://doi.org/10.1016/j.jclepro.2018.10.147

Davis, S. J., Lewis, N. S., Shaner, M., Aggarwal, S., Arent, D., Azevedo, I. L., Benson, S. M., Bradley, T., Brouwer, J., Chiang, Y.-M., Clack, C. T. M., Cohen, A., Doig, S., Edmonds, J., Fennell, P., Field, C. B., Hannegan, B., Hodge, B.-M., Hoffert, M. I., … Caldeira, K. (2018). Net-zero emissions energy systems. *Science*, *360*(6396), eaas9793. https://doi.org/10.1126/science.aas9793

Diffenbaugh, N. S., & Barnes, E. A. (2023). Data-driven predictions of the time remaining until critical global warming thresholds are reached. *Proceedings of the National Academy of Sciences*, *120*(6), e2207183120. https://doi.org/10.1073/pnas.2207183120

Đula, I., Videira, N., & Größler, A. (2019). Degrowth dynamics: Modelling policy proposals with system dynamics. *Journal of Simulation*, *15*(1–2), 93–129. https://doi.org/10.1080/17477778.2019.1646108

EASA. (2022). *European aviation environmental report 2022.* doi: 10.2822/04357. https://www.easa.europa.eu/eco/sites/default/files/2023-02/230217_EASA%20EAER%202022.pdf

Eurocontrol. (2022a). *Aviation outlook 2050: Main report*. https://www.eurocontrol.int/publication/eurocontrol-aviation-outlook-2050

Eurocontrol. (2022b). *Forecast update 2022-2024: Recovery from COVID-19 and Russian invasion of Ukraine*. https://www.eurocontrol.int/publication/eurocontrol-forecast-update-2022-2024

Finance & Trade Watch. (2017). *The illusion of green flying*. https://stay-grounded.org/wp-content/uploads/2019/02/The-Illusion-of-Green-Flying.pdf

Fitzpatrick, N., Parrique, T., & Cosme, I. (2022). Exploring degrowth policy proposals: A systematic mapping with thematic synthesis. *Journal of Cleaner Production*, *365*, 132764. https://doi.org/10.1016/j.jclepro.2022.132764

Foxon, T. J., Reed, M. S., & Stringer, L. C. (2009). Governing long-term social–ecological change: What can the adaptive management and transition management approaches learn from each other? *Environmental Policy and Governance*, *19*(1), 3–20. https://doi.org/10.1002/eet.496

Funtowicz, S. O., & Ravetz, J. R. (1993). Science for the post-normal age. *Futures*, *25*(7), 739–755. https://doi.org/10.1016/0016-3287(93)90022-L

Glenn, J., Kamara, K., Umar, Z. A., Chahine, T., Daulaire, N., & Bossert, T. (2020). Applied systems thinking: A viable approach to identify leverage points for accelerating progress towards ending neglected tropical diseases. *Health Research Policy and Systems*, *18*(1), 56. https://doi.org/10.1186/s12961-020-00570-4

Gössling, S., & Humpe, A. (2023). Net-zero aviation: Time for a new business model? *Journal of Air Transport Management*, *107*, 102353. https://doi.org/10.1016/j.jairtraman.2022.102353

Griggs, S., & Howarth, D. (2023). *Contesting aviation expansion: Depoliticisation, technologies of government and post-aviation futures.* Policy Press. https://bristoluniversitypress.co.uk/contesting-airport-expansion

Hickel, J. (2020). What does degrowth mean? A few points of clarification. *Globalizations*, *18*(7), 1105–1111. https://doi.org/10.1080/14747731.2020.1812222

Hickel, J., & Kallis, G. (2019). Is green growth possible? *New Political Economy*, *25*(4), 469–486. https://doi.org/10.1080/13563467.2019.1598964

Holemans, D. (Ed.). (2022). *A European just transition for a better world*. Green European Foundation. https://www.greenhousethinktank.org/content/files/2022/05/JustTransitionBook.pdf

Huete, J., Nalianda, D., & Pilidis, P. (2021). Propulsion system integration for a first-generation hydrogen civil airliner? *The Aeronautical Journal*, *125*(1291), 1654–1665. https://doi.org/10.1017/aer.2021.36

IATA. (n.d.). *The importance of air transport to the United States*. https://www.iata.org/en/iata-repository/publications/economic-reports/the-united-states--value-of-aviation/

InfluenceMap. (2021). *The aviation industry and European climate policy*. https://influencemap.org/report/Aviation-Industry-Lobbying-European-Climate-Policy-131378131d9503b4d32b365e54756351

IPCC. (2023). *Climate change 2023: Synthesis report*. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee, & J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115. https://doi.org/10.59327/IPCC/AR6-9789291691647

Katz-Rosene, R., & Ambe-Uva, T. (2023). Degrowth, air travel, and global environmental governance: Scaffolding a multilateral agreement for a smaller and more sustainable aviation sector. *Global Environmental Politics*, *23*(4), 119–140. https://doi.org/10.1162/glep_a_00714

Kerkhof, M., & Wieczorek, A. (2005). Learning and stakeholder participation in transition processes towards sustainability: Methodological considerations. *Technological Forecasting and Social Change*, *72*, 733–747. https://doi.org/10.1016/j.techfore.2004.10.002

Kieft, A., Harmsen, R., & Hekkert, M. P. (2020). Toward ranking interventions for Technological Innovation Systems via the concept of Leverage Points. *Technological Forecasting and Social Change*, *153*, 119466. https://doi.org/10.1016/j.techfore.2018.09.021

Kim, D. H. (1999). *Introduction to systems thinking*. https://thesystemsthinker.com/wp-content/uploads/2016/03/Introduction-to-Systems-Thinking-IMS013Epk.pdf

Király, G., Köves, A., Pataki, G., & Kiss, G. (2016). Assessing the participatory potential of systems mapping. *Systems Research and Behavioral Science*, *33*(4), 496–514. https://doi.org/10.1002/sres.2374

Kothari, A., Demaria, F., & Acosta, A. (2014). Buen Vivir, Degrowth and Ecological Swaraj: Alternatives to sustainable development and the Green Economy. *Development*, *57*(3), 362–375. https://doi.org/10.1057/dev.2015.24

Köves, A., & Bajmócy, Z. (2022). The end of business-as-usual? – A critical review of the air transport industry's climate strategy for 2050 from the perspectives of Degrowth. *Sustainable Production and Consumption*, *29*, 228–238. https://doi.org/10.1016/j.spc.2021.10.010

Lyle, C. (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. https://doi.org/10.1163/18786561-00801004

Meadows, D. (1999). *Leverage points: Places to intervene in a system*. The Sustainability Institute. https://donellameadows.org/wp-content/userfiles/Leverage_Points.pdf

Nazari, M. T., Mazutti, J., Basso, L. G., Colla, L. M., & Brandli, L. (2021). Biofuels and their connections with the sustainable development goals: A bibliometric and systematic review. *Environment, Development and Sustainability*, *23*(8), 11139–11156. https://doi.org/10.1007/s10668-020-01110-4

NLR and SEO Amsterdam Economics. (2021). *Destination 2050: A route to net zero European aviation*. https://www.destination2050.eu/report

Otero, I., Rigal, S., Pereira, L., Kim, H., Gamboa, G., Tello, E., & Grêt-Regamey, A. (2022). *Degrowth scenarios for biodiversity? Some methodological steps and a call for collaboration*. SocArXiv. https://doi.org/10.31235/osf.io/fcvpd

Parrique, T. (2019). *The political economy of degrowth* (NNT: 2019CLFAD003). [Doctoral thesis, Stockholm University]. https://theses.hal.science/tel-02499463

Peeters, P., Higham, J., Kutzner, D., Cohen, S., & Gössling, S. (2016). Are technology myths stalling aviation climate policy? *Transportation Research Part D: Transport and Environment*, *44*, 30–42. https://doi.org/10.1016/j.trd.2016.02.004

Roxas, F. M. Y., Rivera, J. P. R., & Gutierrez, E. L. M. (2019). Locating potential leverage points in a systems thinking causal loop diagram toward policy intervention. *World Futures*, *75*(8), 609–631. https://doi.org/10.1080/02604027.2019.1654784

Safe Landing. (n.d.). *About us.* https://safe-landing.org/about-us/

Scheelhaase, J., & Maertens, S. (2020). How to improve the global 'Carbon Offsetting and Reduction Scheme for International Aviation' (CORSIA)? *Transportation Research Procedia*, *51*, 108–117. https://doi.org/10.1016/j.trpro.2020.11.013

Schmidt, P., Batteiger, V., Roth, A., Weindorf, W., & Raksha, T. (2018). Power-to-liquids as renewable fuel option for aviation: A review. *Chemie Ingenieur Technik*, *90*(1–2), 127–140. https://doi.org/10.1002/cite.201700129

Stay Grounded. (2019). *Degrowth of aviation: Reducing air travel in a just way*. https://stay-grounded.org/report-degrowth-of-aviation/

Transport & Environment. (2022a). *Non-CO2 effects of aviation: Time to finally address aviation's full climate impact*. [C.L. de la Osa (author)]. https://www.transportenvironment.org/discover/non-co2-effects-of-aviation-time-to-finally-address-aviations-full-climate-impact/

Transport & Environment. (2022b). *Roadmap to climate neutral aviation in Europe.* https://www.transportenvironment.org/wp-content/uploads/2022/03/TE-aviation-decarbonisation-roadmap-FINAL.pdf

van der Wal, J. M., Borkulo, C. D. van, Deserno, M. K., Breedvelt, J. J. F., Lees, M., Lokman, J. C., Borsboom, D., Denys, D., Holst, R. J. van, Smidt, M. P., Stronks, K., Lucassen, P. J., Weert, J. C. M. van, Sloot, P. M. A., Bockting, C. L., & Wiers, R. W. (2021). Advancing urban mental health research: From complexity science to actionable targets for intervention. *The Lancet Psychiatry*, *8*(11), 991–1000. https://doi.org/10.1016/S2215-0366(21)00047-X

Videira, N., Schneider, F., Sekulova, F., & Kallis, G. (2014). Improving understanding on degrowth pathways: An exploratory study using collaborative causal models. *Futures*, *55*, 58–77. https://doi.org/10.1016/j.futures.2013.11.001

Viswanathan, V., & Knapp, B. M. (2019). Potential for electric aircraft. *Nature Sustainability*, *2*(2), Article 2. https://doi.org/10.1038/s41893-019-0233-2

Waddington, E., Merret, J.M., & Ansell, P.J. (2021). *Impact of LH_2 fuel cell-electric propulsion on aircraft configuration and integration*. AIAA 2021-2409. doi: 10.2514/6.2021-2409. https://arc.aiaa.org/doi/abs/10.2514/6.2021-2409

Warnecke, C., Schneider, L., Day, T., La Hoz Theuer, S., & Fearnehough, H. (2019). Robust eligibility criteria essential for new global scheme to offset aviation emissions. *Nature Climate Change*, *9*(3), Article 3. https://doi.org/10.1038/s41558-019-0415-y

Appendix A

Informed consent form for interviews.

This consent form is to ensure that you are aware of the nature of this interview and your rights as an interviewee. This interview is for an academic study on sustainable pathways for the European aviation sector. The study is conducted by Anya Al-Salem, who is a student in the MSc Sustainable Development programme at Utrecht University and is supervised by Dr. Robert Harmsen.

The interview will be approximately 45 minutes long. Participation in this interview is voluntary and you can quit the interview at any time without giving a reason and without penalty. Your answers to the questions will be shared with the research team. We will process your personal data confidentially and in accordance with data protection legislation (the General Data Protection Regulation and Personal Data Act). Please respond to the questions honestly and feel free to say or write anything you like. Please feel free to skip questions you do not feel comfortable answering. You can also ask the interviewer to clarify or explain questions you find unclear before providing an answer.

By signing this form, you consent to being recorded throughout the interview. The recording will be stored on a secured and encrypted server of Utrecht University and not shared beyond the context of this study. If you wish, your name and/or organisation will be anonymised. You can withdraw your answers and leave at any time. The data you provide will be used for writing a master's thesis report and may be used for other scientific purposes such as a publication in a scientific journal or presentation at academic conferences.

I confirm that:

- I am satisfied with the received information about the research;
- I have no further questions about the research at this moment;
- I had the opportunity to think carefully about participating in the study;

I agree to participate in the study: YES / NO

I prefer that my full name is anonymised: YES / NO

I prefer that my organisation is anonymised: YES / NO

Print Name: ______________________________

Signature: _______________________________ Date: _________________

Appendix B

Anonymised list of interview participants, presented in the order they were conducted.

1. Climate journalist focusing on aviation; author of a book that reveals the connection between nationalism and the aviation industry in the Netherlands.
2. Degrowth researcher; co-author of an academic article critiquing aviation from the perspective of degrowth.
3. Policy coordinator for aviation at a Dutch government body.
4. Climate activist working against misleading advertising in the aviation industry.
5. Aviation policy officer at an NGO campaigning for sustainable transportation in Europe.
6. Researcher of sustainability transitions; co-author of an academic article critiquing aviation from the perspective of degrowth.
7. Analyst & developer for climate change mitigation with previous experience in air transport and operations and aerospace engineering.
8. Sustainable aviation policy manager at an NGO campaigning for sustainable transportation in Europe.
9. Aerospace engineering professor advocating for degrowth of aviation.
10. PhD researcher of the bottom-up movement to reduce flying in Sweden.
11. Climate activist; co-organiser of an airport protest in the Netherlands.
12. Aviation law professional.
13. Climate change analyst at an organisation investigating corporate climate policy influence.
14. Sustainable aviation manager at n NGO campaigning for sustainable transportation in Europe.
15. Sustainability director at a Dutch railway organisation.
16. Analyst at an organisation developing sustainable aviation fuels.
17. PhD researcher of socio-ecological transport policy.
18. Co-founder of an organisation promoting a just transition for aviation workers.

19. Researcher of carbon lock-in in transport systems.
20. Managing director and co-founder of a night train company.
21. Aviation innovation researcher.
22. Airport development and planning specialist at a major European airport.
23. Greenwashing and team coordinator at a grassroots organisation campaigning for degrowth of aviation.
24. Travel policy specialist at a grassroots organisation campaigning for degrowth of aviation.
25. Head of intermodal development at a major European airline.

Appendix C

Additional feedback loops.

Table C1. The seven feedback loops (one reinforcing and six balancing feedback loops) in the CLD (Figure 3) that do not include any of the problem variables.

Reinforcing feedback loop	
Label	**Variables**
R1-C	Normalisation of flying → (-) Aviation industry lobbying → (-) Regulation of the aviation industry → (+) Production costs → (+) Private funding → (+) Technological innovation → (+) Greenwashing → (+) Normalisation of flying
Balancing feedback loops	
Label	**Variables**
B1-C	Production costs → (+) Private funding → (+) Technological innovation → (-) Production costs
B2-C	Airline ticket prices → (-) Normalisation of flying → (-) Aviation industry lobbying → (-) Regulation of the aviation industry → (+) Airline ticket prices
B3-C	Airline ticket prices → (-) Normalisation of flying → (-) Aviation industry lobbying → (-) Regulation of the aviation industry → (+) Production costs → (+) Airline ticket prices
B4-C	Airline ticket prices → (-) Normalisation of flying → (-) Aviation industry lobbying → (-) Regulation of the aviation industry → (-) State aid for aviation → (-) Airline ticket prices
B5-C	Normalisation of flying → (-) Aviation industry lobbying → (-) Regulation of the aviation industry → (-) State aid for aviation → (+) Technological innovation → (+) Greenwashing → (+) Normalisation of flying
B6-C	Normalisation of flying → (-) Aviation industry lobbying → (-) Regulation of the aviation industry → (-) State aid for aviation → (+) Technological innovation → (-) Production costs → (+) Airline ticket prices → (-) Normalisation of flying

Note: Each feedback loop is labelled with 'R' (reinforcing) or 'B' (balancing). A positive causal effect is indicated by '→ (+)', while a negative causal effect is indicated by '→ (-)'. For more information on how to interpret feedback loops, please see Section 3.1.1 (Figure 1).

The feedback loops present in the CLD (Figure 3) that were not addressed in Chapter 5 are presented in Table C1. The only variable included in these feedback loops that is not already defined in Table 1 is the 'greenwashing' variable (B5-C, R1-C), which during the workshop was defined as an inconsistency between a company's 'green claims' (i.e., statements made by a company highlighting its contribution to environmental sustainability) and its 'green activities' (i.e., green investments and policy engagement around issues concerning environmental sustainability). In the European aviation sector, this can be illustrated by airlines marketing themselves as 'sustainable' while actively lobbying against climate policy (Interviews #4 and #13; Appendix B).

Most of the causal links illustrated in Table C1 are already explained in Section 5.1. The two that are not are the positive link between the 'technological innovation' and 'greenwashing' variables, and the positive link between the 'greenwashing' and 'normalisation of flying' variables. The first of these was established during the workshop to illustrate how technological innovations that reduce the climate impacts of aviation (e.g., more efficient engine technologies) create opportunities for the aviation industry to promote the 'green growth' narrative, while continuing to lobby against stringent climate regulation. Furthermore, the positive effect of greenwashing on the normalisation of flying was included to illustrate how greenwashing can reduce environmentally conscious people's cognitive dissonance around flying, thereby perpetuating its perceived normalcy (Interview #4).