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A Study on Low-Carbon Aviation Fuels in the United States: Economic Potential and Challenges Facing Consumer Awareness and Favorability

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Abstract

This is a study of consumer perception and willingness to pay a premium for low-carbon aviation fuels. Commercial aviation is among the fastest growing contributors to anthropogenic climate change and low-carbon drop-in fuels are among the technologies with potential to address this issue. This thesis includes an introduction of concept, an economic evaluation of the marketplace, applications of relevant academic theory, a description of research method, (an online survey distributed to an anonymous and broad cohort) as well as results and conclusions. Study participants had their awareness of low-carbon drop-in fuels and willingness to pay a ticket surcharge for these fuels evaluated at baseline and after exposure to information about the environmental impact of aviation and the potential for low-carbon fuels to ameliorate this impact. The results of the study were that willingness to pay increased by a statistically significant amount post-exposure, confirming the authors hypothesis with regard to the research question.

Keywords: Biofuels, Low-carbon drop-in fuels, Aviation, U.S., Transport, Greenhouse Gas Emissions Reduction

Table of Contents

List of Figures

List of Abbreviations

100 LL	100-Low-Lead (leaded gasoline used in aviation)
CH_4	Methane
CO_2	Carbon Dioxide
COP21	2015 United Nations Climate Change Conference
COVID-19	SARS COV2 Novel Coronavirus 2019
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
GHG	Greenhouse Gases (Mainly CO_2, CH_4 and NO_x)
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICCT	International Council on Clean Transportation
IEA	International Energy Agency
IPCC	The Intergovernmental Panel on Climate Change
Mtoe	Million Tonnes of Oil Equivalent
NASA	National Aeronautic and Space Administration
NO_x	Nitrogen Oxides
USD	United States Dollar
USDA	U.S. Department of Agriculture
WTI	West Texas Intermediate Crude Oil

Foreword

This research paper and study began before the emergence of the novel Coronavirus known as COVID-19. At present, the global economic consequences, at least in the short to medium term, appear significant. Both Goldman Sachs and JP Morgan have forecasted a recession in the U.S. with the potential of shrinking the GDP by up to 5% in the 2nd quarter of 2020 (Winck, 2020). The impacts of Coronavirus on the U.S. and global air travel have been and are expected to be significant (ICAO, 2020). American Airlines has cut international and domestic capacity by 75 and 30 percent, respectively, United Airlines has cut total flight capacity by 50 percent, and Delta 40 percent. The capacity reductions within commercial aviation are expected to persist as long as the global COVID-19 situation impacts travel behavior and the financial condition of airlines.

Chapter 1: Introduction

1.1 Background

Oil and hydrocarbons derived from it have formed the central pillar of the global energy landscape since the decline of the typically coal-fired steam engine in the early 20th century (Pratt, 2008). The 20th century was characterized by significant and consistent growth in oil demand, catalyzed in part by the advent and mass production of the automobile. During the bulk of the 20th century, the primary marketing focus of oil majors was on their role in powering economic expansion and prosperity with minimal regard to environmental impact. The 1950s and 60s, in particular, were marked by profound suburbanization and urban sprawl affecting the developed economies of North America and Europe with automobiles powered by gasoline and diesel, becoming a ubiquitous presence in middle-income homes. While oil and its byproducts powered robust global economic growth and brought rapid global transportation to the masses, science began to discover significant negative externalities, most notably anthropogenic climate change caused by the gases released from fossil fuel consumption, which came to be known as greenhouse gases (GHG). GHG include gases such as Carbon Dioxide (CO_2), Nitrogen Oxides (NO_x), Methane (CH_4), among others, and came to be known as for their ability to trap heat in the lower atmosphere causing observable warming of the global climate. As the global population has taken to the skies with ever greater frequency, the contribution of aviation toward deleterious changes in the earth's climate has continued to grow. Accordingly, means and methods of reducing this impact have become a promising area for academic and scientific research.

In June of 1988, NASA scientist James Hansen testified to a Senate committee that there was a direct linkage between man-made emissions of GHG and observed increases in global temperature (Shabecoff, 1988). This testimony and the coverage thereof is credited with bringing widespread attention to the issue of man-made climate change, primarily as a result of fossil fuel production and consumption. Moreover, a 1988 internal report from Shell Oil titled *The Greenhouse Effect*, uncovered by Dutch journalist Jelmer Mommers with *De Correspondent*, and posted on the Climate Files website, acknowledged on page 1 that fossil fuel combustion is the primary source of CO_2 in the atmosphere.

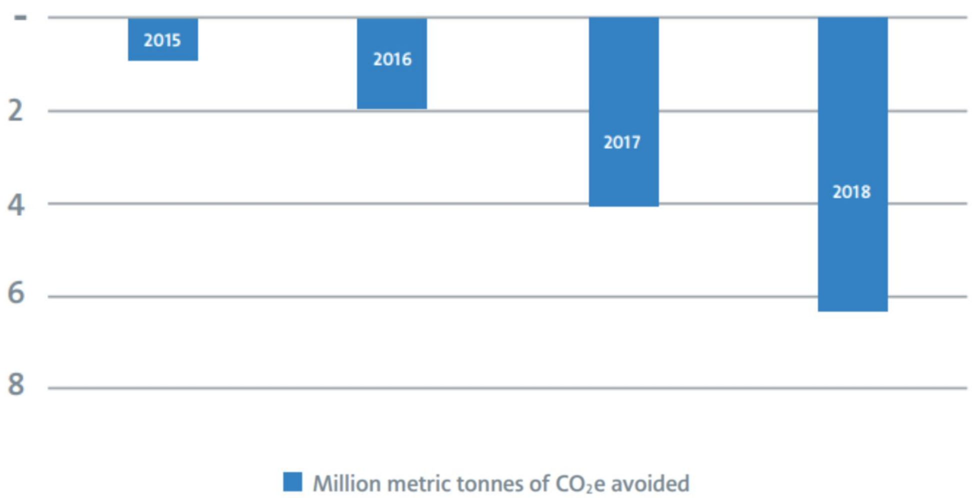
On July 7th of 2008, Brent Crude hit its all-time peak of $147.27 USD, and there were forecasts from reputable contemporary prognosticators predicting that oil would reach $200 USD and above (Story, 2008). These forecasts proved inaccurate due to the confluence of several factors including the unlocking of new supply utilizing hydraulic fracturing or "fracking" technology, a softening of demand resulting from the Great Recession and demand pressure from regulations mandating increased efficiency in the automotive, trucking and shipping sectors (Rogoff, 2016). There is a positive correlation between higher oil prices and increased investment in petroleum alternatives, such as low-carbon liquid fuels due to market pressures for cost competitiveness. Higher oil prices allow alternatives to be competitive based on price, however the imperative of GHG emissions reduction remains regardless of the present status of the oil market. Accordingly, researching the willingness of the flying public to absorb higher prices in pursuit of emissions reductions is worthwhile.

As countries strengthened their commitments to take action on the issue of climate change at the COP21 in 2015 in Paris, aviation and its role in climate change have come into sharper focus. Dr. Martin Cames, Head of the Energy & Climate Division at the Institute for Applied Ecology in Berlin, stressed that efforts by the International Civil Aviation Organization (ICAO) have fallen short of global mitigation requirements. His research suggests that in order to attain global mitigation requirements by staying below an increase of 2°C, aviation emissions should decrease by 41% by 2050. In a like manner, Alice Larkin, Head of the School of Engineering and Professor of Climate Science and Energy Policy, emphasized the challenges for mitigation opportunities facing aviation, given the limited short-term technical options ("Coverage of Selected Side Events at UNFCCC COP 21", n.d.).

Air carriers are under pressure to continue delivering the low prices that customers have come to expect while also making investments that lead to fuel savings. Generally, this has been achieved through investment in newer, more efficient aircraft. As an example, American Airlines has reduced carbon emissions by 6 million tons since 2014 due to fuel efficiency improvements, as shown in *Figure 1* (American Airlines, 2019). In contrast, U.S. GHG emissions totaled 5,268 million metric tons of CO_2 (U.S. Environmental Protection Agency, 2020). It is, however, evident that this fleet modernization alone will be insufficient to drive the 26 to 28 percent emissions reduction below 2005 levels the U.S. had pledged to during Obama's administration.

Figure 1

Tonnes of CO_2 emissions avoided by American Airlines due to fuel efficiency improvements since 2014.



Note. Adapted from “2018 Corporate Responsibility Report” by American Airlines, 2018 (http://s21.q4cdn.com/616071541/files/doc_downloads/crr/CRR-Report-2018.pdf).

1.2 Research Question

Aviation is one of the fastest growing sources of greenhouse gas emissions globally and despite improvements in aircraft efficiency this trend is expected to continue (Environmental and Energy Study Institute, 2019). The United States represents the largest single source of aviation emissions due to its geography and deficiencies in ground-based public transportation. Low-carbon liquid aviation fuels are an emerging technology that has been the recipient of significant investment by airlines. In the present low oil-price environment cost poses a significant challenge for airlines which would be significantly addressed if it could be passed to consumers. Accordingly, our research question is:

What is the present level of favorability and awareness of low-carbon drop-in aviation biofuels in the U.S. as measured by passenger willingness to pay a fuel surcharge for a flight operated with these fuels to reduce their carbon footprint while flying, and can this be enhanced by airlines through an informational marketing approach?

1.3 Organization of the Thesis

Chapter one explored background considerations related to low-carbon drop-in fuels in U.S. commercial aviation. The second chapter of this study provides a general technical overview and discusses market conditions surrounding low-carbon drop-in aviation biofuels in the U.S in the context of emissions reduction targets. The third chapter explores relevant academic theories that form the theoretical foundation of the study. The fourth chapter presents the research study design and methods. The fifth chapter discusses the findings of the study and presents the conclusions drawn therefrom. This thesis concludes with discussion of findings and exploration of avenues of further research.

Chapter 2: Context & Market

2.1 What are low-carbon drop-in fuels? Definitions and thresholds

Low-carbon drop-in fuels are liquid fuels that are able to deliver a reduction in emissions of carbon dioxide and other GHG that can be utilized in existing internal combustion engines without substantial modification ("Creating a sustainable future with aviation biofuels," n.d.). As the primary focus of this study is on the potential for usage of these fuels in aviation, emphasis is placed on the criteria that must be met for fuels to be considered low-carbon, sustainable, and to meet the definition of a drop-in fuel. These fuels can be produced through a range of technological processes using a wide variety of non-fossil fuel feedstocks.

Given the highly variable atmospheric environments in which commercial aircraft operate and a strict imperative of safety, it is essential that alternative fuels achieve performance equivalence with standard JET-A. JET-A is the standard marketplace term for the civilian jet fuel specification used in the U.S. and at several large airports in Canada. It differs slightly from the Jet-A1 specification that is the international standard but is functionally equivalent in modern commercial aircraft.

In some rural markets including the state of Alaska, small airlines continue to operate piston-engine aircraft as part of essential service to remote communities. These aircraft have traditionally been powered by 100-LL which is a high octane gasoline product. 100-LL is the only fuel still in common use that contains tetraethyl lead While efforts have been made by companies including to develop a low-carbon drop-in alternative to 100 LL that also avoid the public health risks of 100 LL, none have been commercially successful as of the present time. Further, piston-powered aircraft are responsible for only ~13 percent of the total CO_2 emissions from aviation and as such do not represent a significant target in efforts to mitigate anthropogenic climate change (Aircraft Owners and Pilots Association, 2008).

Considering that U.S. airlines fly domestic routes between destinations with as much as a 20 degrees Celsius difference in annual average temperature and as much as a 40 degree difference between takeoff and touchdown, it is essential that any alternative jet fuels meet stringent performance parameters. These are set forth in the specifications for aviation fuel by ASTM. ASTM, formerly known as the American Society of Testing and Materials, is responsible for setting chemical and material standards in 40 participant countries. By meeting these specifications the producers of low-carbon drop-in fuels demonstrate product equivalency such that the fuels can be utilized without modification to aircraft systems and in blends with standard JET A as appropriate and available.

Low-carbon drop-in fuels must achieve a material reduction in lifecycle carbon emissions compared to traditional fossil-based jet fuel and meet comprehensive sustainability criteria, such as those of the Roundtable on Sustainable Biomaterials (RSB) certification. The actual emissions reduction achieved often depends on the extent to which the fuels are blended with standard jet fuel which can depend on varying fuel availability at airports. In order for a low-carbon alternative fuel to truly satisfy drop-in criteria it ideally must be able to operate in a range of blends with standard petroleum based jet-fuel.

According to the National Academies of Sciences, Engineering, Medicine, Aeronautics Space Engineering Board, and Committee on Propulsion Energy Systems to Reduce Commercial Aviation Carbon Emissions (2016), "Drop-in jet fuels have aggregate properties that are essentially equivalent to those of conventional (petroleum-based) jet fuels. As such, drop-in fuels are fully miscible with conventional jet fuels, and they are fully compatible with existing aircraft and the existing fuel infrastructure (tanks, pipelines, equipment, etc.)" (p.71). A degree of variation in the chemical properties of the fuel is tolerated to accommodate differences in raw sources of petroleum and the refining thereof worldwide. This tolerance allows for the introduction of fuel components produced from non-petroleum feedstocks, while still delivering the critical qualities necessary to be used to fuel jet aircraft."

Qantas, the flag carrier and largest airline of Australia, operated its first biofuel-powered trans-Pacific flight between Australia and the United States in January 2018. The flight was powered by 24,000 kg of blended aviation biofuel. This flight alone saved 18,000 kg in carbon emissions in comparison to regular aviation fuel (Creating a sustainable future with aviation biofuels, n.d.).

2.2 Relevance of this research

While there has been some limited research into the “general population’s” willingness to pay surcharges for flights operated on biofuels there are gaps in the research that this study is meant to address (Fitzgerald, 2019). The focus herein was to evaluate in greater depth the extent to which being presented with information about the GHG reduction potential of low-carbon fuels in aviation changed willingness to pay as compared to baseline. Considering that emissions reduction figures themselves are an inherently abstract concept without context, this study placed potential emissions reductions from low-carbon fuels in straightforward and easily visualized context.

Further, this study was targeted toward a more specific and tailored target audience. This audience consisted of the U.S. market exclusively and only those likely to have the means, as measured by income, to fly consistently and consequently to have larger baseline carbon footprints. The intent behind this choice was to evaluate the views of those with the purchasing power to impact airlines' decisions regarding low-carbon fuels. Further, the well established geographical differences in concern about climate change and the well-established lag of the U.S. in this regard adds urgency to the imperative of reducing emissions from aviation in this market. This presents the opportunity to compare and contrast the results with those of previous research which found that the relatively small yet high income Norwegian market showed a high level of willingness to consider environmental impact in travel decisions (Higham & Cohen, 2011).

2.2.1 Current global emissions reduction targets

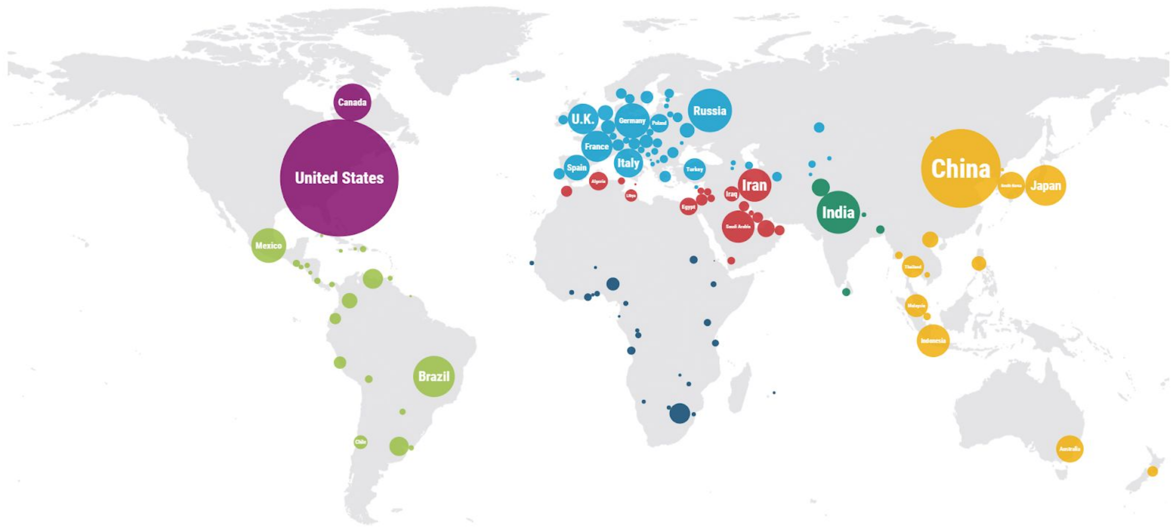
The United Nations Intergovernmental Panel on Climate Change (IPCC), in its 2018 Special Report "*Global Warming of 1.5°C*" stressed an "urgent" call to action to reduce CO_2 emissions to mitigate the impacts of climate change, including the airline industry, which accounts for approximately 2 percent of global CO_2 emissions. In order to achieve this goal, it is estimated that a 50 percent net reduction of net aviation CO_2 emissions is necessary relative to 2005 levels. Air transport is presently one of the fastest-growing sources of CO_2 emissions and also a significant source of short-term non-CO_2 greenhouse gases (Reducing Emissions from Aviation, n.d.).

The four largest commercial airlines in the world, both by fleet size and number of passengers carried, are based in the U.S. These are American Airlines, Delta Air Lines, United Airlines, and Southwest Airlines (IATA, 2019). According to the International Council on Clean Transportation (ICCT), in 2018, commercial flights in the U.S. resulted in emissions of 182 million metric tons of CO_2 (ICCT 2019). This was 23% of the global total and an amount that exceeds the total national CO_2 emissions of Denmark, Norway, and Sweden combined. Flights within North America also presently operate with a relatively higher carbon intensity measured in grams of CO_2 per passenger kilometer than flights within Asia or Europe. The vast area of the U.S. in combination with the lack of viable alternatives to air travel over most routes (in part due to a lack of high-speed rail) means that a means must be identified for the carbon intensity of air travel to be reduced in order for emissions reduction targets to be met.

Low-carbon drop-in fuels may present a practical and relatively cost-effective means for achieving these GHG emission reductions (Graver B., Zhang, K., & Rutherford, D., 2019). With these targets in mind, it is worth looking at *Figure 2*, in which the countries with the highest transport emissions around the world can be observed (Wang, S. & Ge, M., 2019). The United States is, therefore, the country with the most transportation emissions in the world, followed by China, Russia, India, Brazil, Japan, Canada, Germany, Mexico, and Iran, are ranked, in descending order. These ten countries alone account for 53% of total worldwide transportation emissions. Not surprisingly, the four largest airlines in the world, both by passengers carried and fleet size, are also American. These are American Airlines, Delta, United Airlines, and Southwest, in that order (Mazareanu, 2020).

Figure 2

Transport Emissions Around the World (in perspective).



Note. From "Everything You Need to Know About the Fastest-Growing Source of Global Emissions: Transport" by the World Resources Institute, 2019 (https://www.wri.org/blog/2019/10/everything-you-need-know-about-fastest-growing-source-global-emissions-transport).

As significant progress has been made in reducing GHG emissions from electricity generation from a gradual but material transition away from coal and toward natural gas and renewables, reducing emissions associated with transportation has proven more challenging (U.S. Environmental Protection Agency, 2017). While there have been significant investments made in electric automobiles, the cumulative emissions reductions remain insufficient. While market-leader Tesla has sold in excess of 500,000 vehicles, the cumulative CO_2 emissions saved are approximately 5 million tons; equivalent to less than one month of U.S. aviation emissions (Bloomberg, 2019).

2.2.2 Present challenges to meeting targets Beyond the Electric Grid

The transition toward electric automobiles has garnered tremendous attention and investment both public and private yet these are not a particularly cost-effective means of reducing emissions (Gillingham & Stock, 2018). Despite the presence of a $7,500 federal tax credit, electric vehicles represented only 1.8% of U.S. sales as of March 2019 (Edison Electric Institute, 2019). Further, with a total fleet lifespan averaging 15 years and a fleet size of 263 million vehicles, even rapid adoption of electric vehicles would be insufficient to rapidly and significantly reduce total GHG emissions from transport.

In order to examine the necessity of low-carbon liquid fuels it is necessary to determine whether GHG emissions reduction targets can be met without these fuels. Even in scenarios involving grand shifts toward mass transit, electric vehicles, and significant efficiency improvements, a need for energy-dense liquid fuels will remain in 2050, where they are expected to account for 80% of transportation fuel. It is the issue of energy density and the limitations of battery technology in combination with the long life-cycles of the commercial aviation fleet that leads to a significant portion of this demand being driven by aviation, which is the focus of this study. Consequently, Fulton et al. (2015) concluded that aggressive efforts to utilize sustainable, low-carbon fuels are an essential part of the future energy mix.

Advancements made in more efficient aircraft through refinements of engine designs and the use of lighter and more aerodynamic materials have delivered some reduction in the GHG footprint of commercial aviation but the pace of growth in the sector before COVID-19 was such that absolute improvements were difficult to achieve. In 2018, U.S.

airlines improved their fuel efficiency by 3 percent but overall emissions from domestic air travel still increased by 7 percent due to sheer demand. This situation is exacerbated in part by emissions reductions targets put forth by ICAO that are considered by the ICCT to be relatively weak and insufficient. ICAO targets requiring emissions intensity reductions of 4 percent over 12 years are minimal influences as compared to market forces expected to drive 10 percent reductions over the same period (Joselow, 2019).

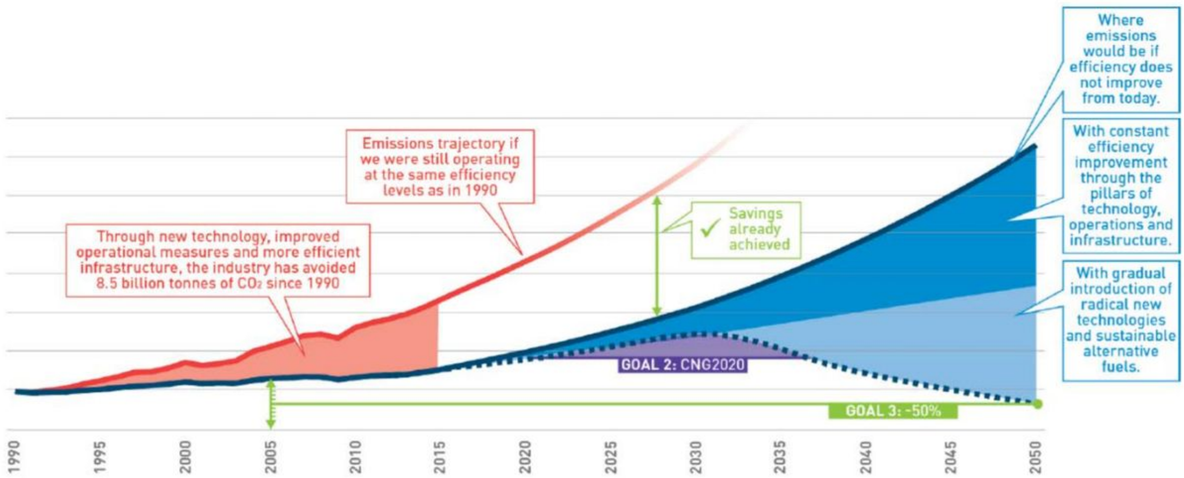
It is difficult to predict the trajectory of recovery in demand, particularly from business travel, however most current projections suggest an eventual recovery. Further, the global economic situation has done great financial damage to companies such as Boeing, Airbus, GE and Rolls Royce among other companies that had been responsible for a significant portion of investments toward improved fuel efficiency (PwC, 2020). This presents a potential opportunity for low-carbon aviation fuels that can deliver emissions reductions without necessitating the purchase of new aircraft or requiring extensive modifications to existing aircraft.

As *Figure 3* shows, sustainable alternative (low-carbon) fuels are urgently needed in order for ambitious reduction to be realized. While advances toward more efficient aircraft and "infrastructure" improvements like more direct GPS based routings have delivered real emissions savings, low-carbon fuels have a demonstrable role to play. The "drop-in" nature of low-carbon biojet fuel delivers scalability and immediate impact. While there has been some development in the direction of electric aircraft, these are not currently commercially viable due to the limitations of current battery technology (Misra, 2017). The energy density of liquid jet fuel in combination with the speed of refueling are factors that present a fundamental challenge to electrified air travel.

An additional source of transport-related emissions, long-haul trucking (primarily powered by diesel), transports 71 percent of goods in the U.S. alone with a gross economic impact of $700 billion USD (Business Insider, 2019). While there are material challenges and uncertainties inherent to the various low-carbon liquid fuel options, their superior energy density relative to batteries ensures a role in long-distance transport, whether by air, sea, or land (Aerospace Resource Central, 2012). A movement toward widespread adoption of sustainably produced low-carbon liquid fuels at a price competitive with petroleum-based fuels is a critical pillar of secure and sustainable low-carbon transport.

Figure 3

Notional industry trends for global emissions from aviation under different scenarios.

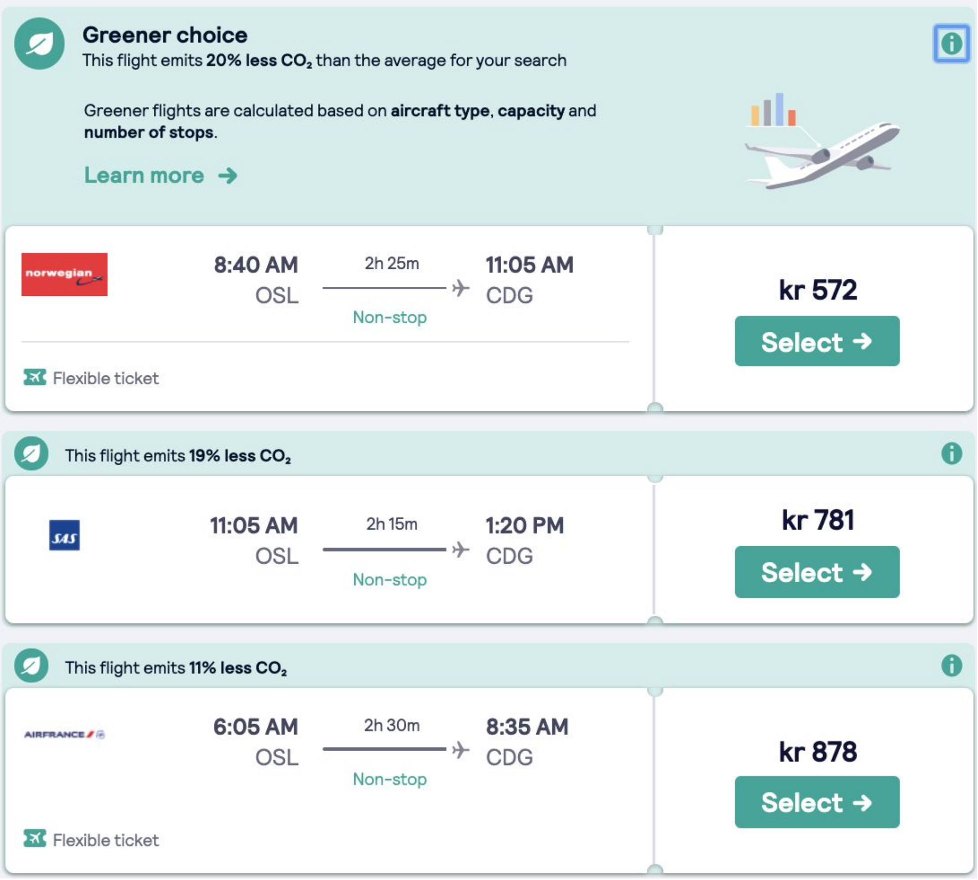


Note. From "Potential Avenues for Significant Biofuels Penetration in the U.S. Aviation Market", by National Renewable Energy Laboratory, 2017 (https://www.nrel.gov/docs/fy17osti/67482.pdf). Copyright 2016 by IATA.

Third party flight search engines like U.K. based Skyscanner, one of the largest in the world, and largest in China, have slowly, but steadily, started implementing solutions to increase the awareness of travelers about their CO_2 emissions. These solutions consist, in the case of Skyscanner, of in-house algorithms that determine based on the trip distance, aircraft model, and fuel used, the total CO_2 emissions per passenger and display this information to those searching for flights. The information that is most prominently presented to customers is the percentage CO_2 reduction offered by a specific flight as shown on *Figure 4* on top of page 19.

Figure 4

Example of Skyscanner's solution to increase the awareness of travelers about their CO_2 emissions.



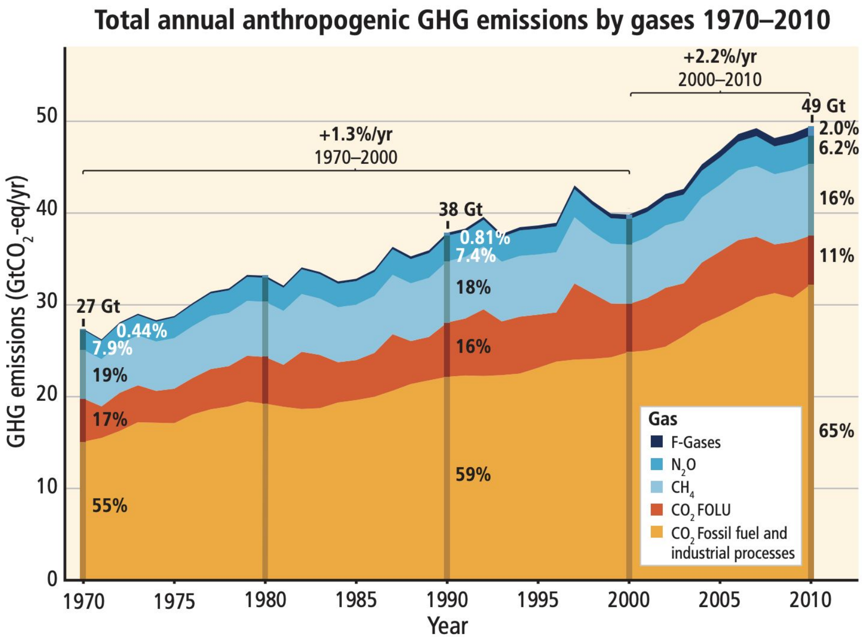
Note. From https://www.skyscanner.com/

2.2.3 Non-CO_2 impacts of aviation on anthropogenic climate change and the role of alternative liquid fuels

The term "radiative forcing" is defined as has been employed in the IPCC Assessments to denote an externally imposed perturbation in the radiative energy budget of the Earth's climate system. (Ramaswamy et al., 2001). These perturbations are caused by changes in the concentrations of radiatively active species (e.g., CO2, aerosols, etc.) and other impacts that affect the radiative energy absorbed by the surface (changes in surface reflection properties, induced by changes in Albedo). In the context of climate change, the term forcing is generally limited to changes in the radiation balance of the surface troposphere system imposed by external factors. For the purposes of this study, these changes are limited to those caused by the combustion of fuel by commercial aircraft and the ways in which the adoption of cleaner fuels can ameliorate these effects.

Figure 5

Total annual anthropogenic GHG emissions by gases 1970–2010.



Note. Adapted from "Climate Change 2014: Synthesis Report" (p.46), by IPCC, 2014 (https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf).

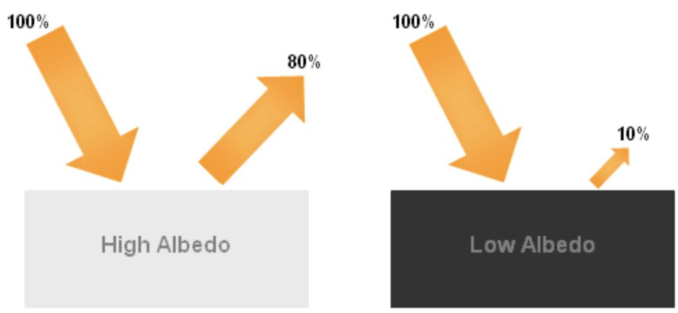
Figure 5 describes the volume of each type of greenhouse gas emitted into the atmosphere. It demonstrates that while CO_2 accounts for the largest portion, N_2O, which is significantly emitted from the combustion of traditional jet fuel, is a significant component of overall emissions.

An important element of evaluating approaches toward reducing the impact of aviation on anthropogenic climate change is to consider non-CO_2 GHG effects. One factor of particular importance is nitrogen oxide or NO_x. NO_x is a pollutant with a much shorter duration in the atmosphere than CO_2 but with short-term effects that are very significant. In fact, research has established that at the present time the climate effects of the non-CO_2 emissions from aviation exceed those of CO_2 itself (Bannon, 2018). Studies have also confirmed that NO_x emissions at flight altitude are a significant contributor to global levels and NO_x disturbances in the atmosphere (Schumann, 1997).

Indirect GHG emissions such as NO_x released at flight altitude have a greater short-term warming potential. This means that claims by the IPCC and lobby groups such as the International Air Transport Association (IATA) of aviation accounting for approximately 2 percent of global CO_2 emissions are not entirely correct. At the present time, the non-CO_2 effects of aviation are not incorporated in international agreements regarding emissions reduction. According to Professor Dr Volker Grewe, researcher at DLR Institute of Atmospheric Physics and chair for climate effects of aviation at Technical University Delft, air traffic contribution to climate change is closer to 5% (Grewe, 2018). This is due to the fact that, in addition to the emission of CO_2, aircraft flying at altitude impact the atmosphere in various ways which have a significant, albeit temporary, additional warming effect (Grewe et al., 2017). Considering that flight schedules are repeated on a daily basis these temporary impacts become effectively permanent and accordingly must be considered when evaluating methods of reducing commercial aviation's impact on the climate.

Figure 6

Albedo.



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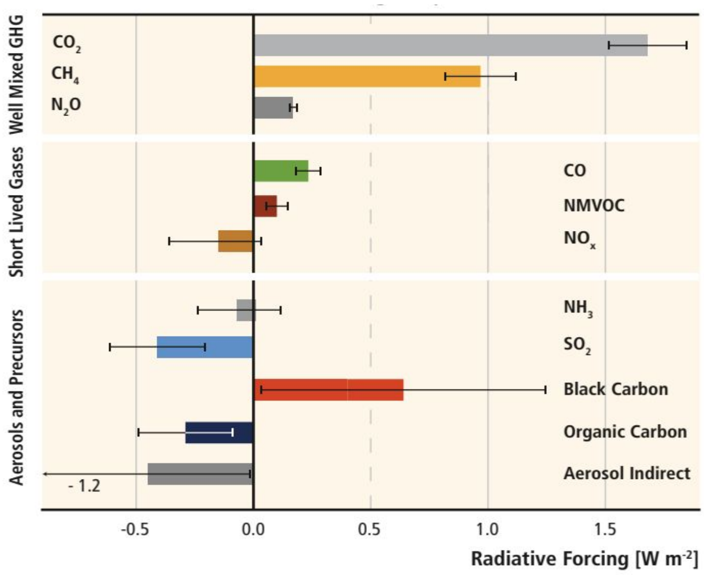
Note. From "Albedo", by North Carolina Climate Office (https://climate.ncsu.edu/edu/Albedo).

The climate effects of carbon go beyond GHG effects and include the role of soot in reducing albedo by making both snow on land and sea ice darker and less reflective. When albedo is reduced through accumulation of soot, snow and ice reflect less incoming solar energy resulting in increased warming. It is this effect that causes black asphalt pavement to be hotter on a summer day than light-colored concrete. A high albedo surface reflects 80% of incoming radiation, while a low albedo surface reflects only 10% of incoming radiation (State Climate Office of North Carolina, n.d).

Reduction of these non-CO_2 emissions is an area of promise for cleaner fuels, including low-carbon drop-in fuels. *Figure 6* illustrates the concept of albedo and its impact on energy balance and heat retention. While the figure uses the pavement analogy described above the relevance to aviation lies in the way in which emissions from aircraft contribute to the creation of fine particles and soot that contribute to the darkening of snow and ice and consequential levels of climate warming (Hansen & Nazarenko, 2004).

Figure 7

Components of radiative forcing.



Note. Adapted from "Climate Change 2014: Synthesis Report" (p.361), by IPCC, 2014 (https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf).

In addition to albedo and CO_2 there are other components of aviation emissions that have an impact on the global climate through their influence on the energy balance in the atmosphere. These other emissions are all part of *radiative forcing* which refers to the ability of atmospheric components to influence the energy balance in the Earth's atmosphere (IPCC, 2014). These components are shown in *Figure 7* and in the case of emissions from combustion of jet fuel most notably include CO_2, NO_2 and black carbon which itself influences albedo as discussed above.

2.2.4 Public awareness of the impact of biofuels in the aviation industry

As part of this research, we will evaluate the level of awareness and favorability of low-carbon aviation fuels amongst the flying public. Given the cost advantages still held by traditional petroleum JET-A, it is likely that some of the costs of utilizing low-carbon fuels would be passed on to the flying public (Gayle & Lin 2017). Accordingly, it is crucial to evaluate customers' willingness to pay" for these low-carbon fuels and which marketing approaches hold potential in increasing this willingness. It is further essential to assess differences in perception demographically to determine which subsets of customers are most willing to bear these increased costs.

In addition to assessing public awareness and favorability, another concept is vital to this study: innovation resistance. In this regard, low-carbon aviation fuels are a recent, novel, innovation as the first flight using a biofuel blend only dates back to 2008 (Le Feuvre, 2019). Heidenreich & Kraemer (2016) concluded that innovation resistance is a significant cause of product failure. Furthermore, Heidenreich, S. et al. (2011) had, in a previous work, further subdivided and differentiated innovation resistance into two types: active and passive.

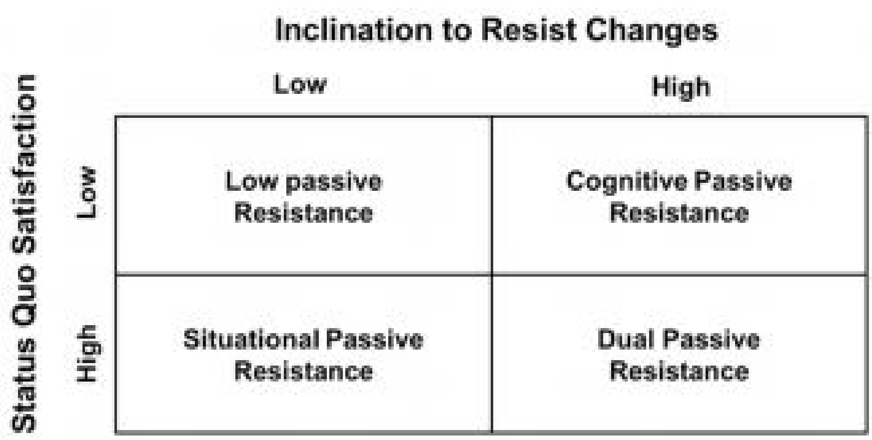
Active innovation resistance is the result of perceived product-specific barriers; it "represents a negative attitude formation, which follows new product evaluation, and which is likely to lead to an innovation rejection" (Heidenreich, S. et al., 2011, p.230). Consequently, a degree of divergence will result when consumers compare their individual expectations to characteristics from the innovation. On the other hand, passive innovation resistance is the initial response of a consumer to an innovation. It forms after the moment of awareness, without considering product-specific factors, and prior to the product (innovation) evaluation.

In other words, passive innovation resistance is the "predisposition to resist evolving from an individual's resistance to change disposition and a status quo satisfaction in the moment of awareness. Active innovation resistance toward low-carbon drop-in fuels is derived mainly from the material "intangibility" inherent to the innovation. The intangibility of low-carbon drop-in fuels is even more so in the aviation industry. These challenges have the potential to be overcome through tailored informational marketing instruments as evaluated in the research element of this study. The objective of this study is to systematically evaluate aspects of passive innovation resistance and product-specific barriers in the formation of active innovation resistance and eventual rejection of the innovation (e.g. the low-carbon drop-in fuels).

It is the increasing dissemination of environmental-friendly products and technologies; the climate change challenges facing the world that are now challenging individuals' predisposition to resist change. In effect, a “green” mindset has gone mainstream. This is particularly the case among those consumers that are middle-aged and younger as evidenced by the demonstrated positive correlation between youth and environmental concern. The extent to which this concern is motivated by personal factors versus social norms remains an emerging area of research.

Figure 8

Types of Passive Innovation Resistance.



Note. From “How to overcome pro-change bias: incorporating passive and active innovation resistance in innovation decision models”, by Talke, K., & Heidenreich, S., 2014, *Journal of Product Innovation Management*, *31*(5), p.898. (https://doi.org/10.1111/jpim.12130).

Fully drop-in, sustainable and energy-dense biomass-based liquid fuels, offered at a price competitive with that of petroleum-based fuels is the ultimate goal to address societal needs around climate change and energy security (Babcock, Marette, & Tréguer, 2011). Specific biofuel pathways will be advanced by a favorable economic and environmental value proposition relative to that of petroleum-based fuels while maintaining performance and reliability. Highly specific and consistent policies addressing feedstocks infrastructure/logistics, funding, and environmental issues have the potential to more efficiently advance the adoption and market penetration of next-generation renewable liquid fuels.

2.3 Present circumstances- policy incentives

According to the U.S. Department of Energy (2017) in the United States, the U.S. Department of Agriculture (USDA), the U.S. Department of Energy (DOE), and the U.S. Navy made an investment of $510 million in 2012 with the purpose of initiating private-sector partnerships for the production of advanced, low-carbon "drop-in" aviation and marine biofuels. Moreover, in 2014, the U.S. Department of Defense (DOD), USDA, and DOE selected candidates, including companies Emerald Biofuels, Fulcrum BioEnergy, and Red Rock Biofuels, for investment toward the construction of biorefineries to produce advanced drop-in biofuels.

The "Farm to Fly" program launched in 2012 is a collaborative effort between the U.S. Department of Agriculture, Boeing Aerospace, and Airlines for America for the promotion of drop-in renewable jet fuels with a goal of producing 1 billion gallons of aviation jet fuel by 2018. The program was extended through 2019 with the Federal Aviation Administration (FAA) and private partners. In addition, the U.S. Department of Defense has included AJF in standard procurement practices since 2014 as part of efforts to bolster the development of commercial opportunities in the biofuel space (U.S. Department of Energy, 2017).

In 2016, the Office of the President released the Federal Alternative Jet Fuels Research and Development Strategy under the National Science and Technology Council. The strategy prioritizes Federal research and development objectives to address relevant technical challenges that inhibit the development, production, and use of economically viable low-carbon aviation fuels that would lead to real emissions reduction (NSTC 2016).

At present, the U.S. government offers a tax credit ranging from \$2,500 to 7,500 USD depending on battery capacity available for the first 200,000 sales from a given electric car manufacturer (Congressional Research Service, 2019). Due to many contributing factors it is difficult to calculate the exact amount of CO_2 saved by this program but EV stalwart Tesla can be used to formulate estimates. In 2019 Tesla announced that the 550,000 vehicles sold in the company's lifetime had saved 4 million tons of CO_2. Paring these figures down to the first 200,000 vehicles that were eligible for the \$7,500 USD federal tax credit suggests that the "subsidy cost" of avoided CO_2 was \$1,031 USD per ton. Considering that transport in total was at 28% the largest sector source of the U.S. CO_2 emissions and is also the fastest growing source of emissions, low-carbon liquid fuels have the potential to be a key pillar of efforts to reduce overall emissions (U.S. Environmental Protection Agency, 2018).

2.3.1 Commitment from airlines and the private sector

The concept of low-carbon liquid fuels in aviation is the beneficiary of relatively strong current participation and investments by airlines (e.g., Cathay Pacific, Southwest Airlines, United, and others), private corporations (e.g., FedEx), and oil companies (e.g., British Petroleum and Shell) in supply chain and technology development (Hammel 2016). A recent example of this outside investment is an offtake agreement between Fulcrum Energy and Air BP, which was announced in November 2016. With this \$30-million agreement, Fulcrum Energy has the funds needed to accelerate the construction schedule for its next renewable jet fuel plant and provide Air BP with 50 million gallons per year of low-carbon, drop-in jet fuel (Biofuels International, 2016).

The emergence of the global COVID-19 pandemic is an unanticipated factor likely to materially influence investment decisions worldwide, including in low-carbon liquid fuels for aviation (Reuters, 2020). Additionally, the present dramatic decline in oil prices is of uncertain depth and duration which leads to uncertainty in the cost-competitiveness of low-carbon liquid fuels in relation to traditional jet fuel (Pavlenko et al., 2019). The ultimate impacts of the present cost environment on the market potential of low-carbon liquid fuels depends to a large degree on the duration of present conditions. An additional present circumstance with as yet undeterminable impacts on low-carbon liquid fuels in U.S. aviation is the financial condition of airlines. Given the dramatic short-term declines in air travel, U.S. airlines are taking drastic action to reduce nonessential capital expenditures. These efforts to reduce expenditure can reasonably be expected to put investments into low-carbon fuels at risk. Uncertainty around both the timing and extent of a return to "normal" conditions in the industry is significant.

Some airlines, especially in European countries with particularly environmentally-engaged customers, have made their specific pledges. SAS has said it will cut emissions by 25 percent by 2030 and is aiming to run domestic flights on biofuels.IAG, which owns British Airways and Spain's Iberia, has pledged to invest $400 million USD on developing alternative fuels over a 20-year period, while United Airlines has said it will spend up to $2 billion USD annually on fuel-efficient aircraft and is working with biofuel producers.

Some airlines, including IAG, parent company of British Airways believe one of the most promising areas is alternative low-carbon fuels, which could be used in existing aircraft, but with a lower carbon footprint. These include biofuels, which can be made from plants, waste or algae, and synthetic fuel, a substance resembling jet fuel that can be manufactured using renewable energy. Others are pinning their hopes on electric aircraft and hybrid battery-fuel designs.

The feedstocks used for fuel production will be waste and residue streams, such as used cooking oil, coming predominantly from regional industries. The facility will run on sustainable hydrogen, produced with water and wind energy. Thanks to these choices, this sustainable aviation fuel delivers a CO_2 reduction of at least 85% as compared to fossil-based jet fuel. KLM's use of low-carbon fuels will also contribute to a material reduction in emissions of ultra-fine particles and sulphur. The construction of this facility is a component of KLM's sustainability objectives and is an important step towards implementing the "Smart & Sustainable" strategic directive which was drafted by twenty leading organizations in the travel and transportation industries. Amsterdam Schiphol airport, eleventh biggest and busiest airport in the world, will also be investing in improvements to enhance its sustainability in line with this strategic objective (KLM, 2019).

2.3.2 United Airlines - Case in Point

United Airlines traces its history to the formation of Varney Air Lines by Walter T. Varney in 1926 (United Airlines. Firsts in Aviation, n.d.). Over the ensuing nine decades United has grown to be the fourth largest airline in North America by passenger volume (Bureau of Transportation Statistics, 2019). From its primary hubs in Newark, New Jersey, Chicago, Illinois and Denver, Colorado, United served in excess of 162 million passengers in 2019 (United Airlines. Corporate Fact Sheet, 2019). In 2019, United operated 4,989 flights daily to 362 destinations in 61 countries (United Airlines Corporate Fact Sheet, n.d.). Given these figures, United is of sufficient size for its fuel choices to impact the marketplace as a whole.

United's contract renewal with World Energy will further assist the airline in achieving its recently announced commitment to reduce its GHG emissions by 50% by 2050. United's pledge to reduce emissions by 50% relative to 2005 represents the equivalent of removing 4.5 million vehicles from the road or the total number of cars in New York City and Los Angeles combined. United's biofuel supply agreements represent more than 50% of the commercial aviation industry's total agreements for sustainable aviation biofuel.

At present, the only one of these technologies that are being used commercially is biofuels, although on a limited scale. AltAir Fuels is a California-based entity that supplies United Airlines with biofuel produced using agricultural waste as a feedstock. United has also partnered with Fulcrum BioEnergy, a Nevada-based entity which is developing waste-to-fuel refineries. “We see this as the future in this space,” says Aaron Robinson, senior sustainability manager at United Airlines. He is optimistic about using waste for biofuels, given that it is cheaper to develop than crops (Conboye & Hook, 2019).

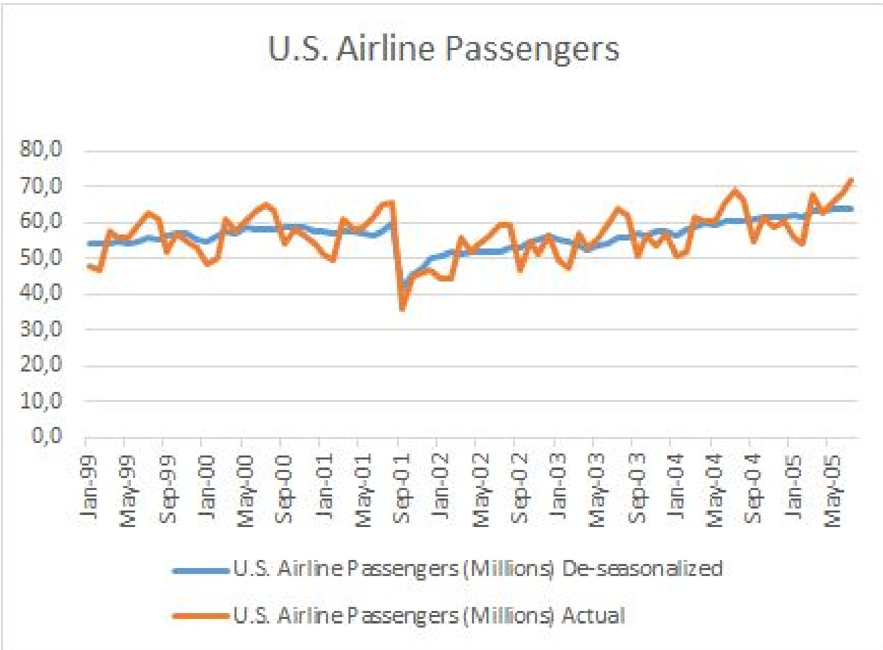
2.3.3 Looking Forward

There is a substantial degree of policy uncertainty in the U.S. pending the result of the 2020 elections, specifically the Presidential election. U.S. President Donald Trump has pledged to remove the U.S. from the 2015 Paris Accords, but due to the withdrawal provision of the Accords, this withdrawal will not take official effect until November of 2020 (Johnson, 2019). The emissions reductions targets specified in the Paris agreement are a reliable potential driver of the uptake of low-carbon liquid fuels (Lee, 2018). The 2020 election will also be of significant importance with regard to the magnitude of potential subsidies for the utilization of low-carbon liquid fuels.

The Trump administration has been broadly hostile toward initiatives and policies intended to reduce GHG emissions, but the potential exists for the pollution reduction benefits of alternative jet fuels to be highlighted. A 2016 study of the health impacts of pollution surrounding the twelve largest airports in California found that a one-standard-deviation increase in carbon monoxide levels led to a $540,000 USD increase in hospital costs among the six million people living within 10 km of those airports (Schlenker & Walker, 2016).

Figure 9

Evolution of Airline Travel in the U.S. Before and After September 11th, 2001.



Note. Adapted from “U.S. Airline Passengers”, by U.S. Department of Transportation, 2017 (https://www.bts.gov/archive/publications/special_reports_and_issue_briefs/issue_briefs/number_13/figure_01).

An additional “wild card” factor looking forward in the short-to-medium term is uncertainty regarding the pace of resolution of the Coronavirus pandemic and the potential for lasting changes to consumers' travel habits. While figures change daily, commercial air travel globally has declined dramatically due to COVID-19. As an example, air traffic at Los Angeles International Airport has declined by 85% due in large part to virus mitigation efforts. While commercial aviation will recover alongside the global economy, there is a historical precedent to suggest that present declines may have a lasting impact. After the terrorist attacks of September 11th 2001, air travel declined dramatically and took a period of three years to return to its previous levels (U.S. Department of Transportation, 2005).

2.3.4 Low-carbon drop-in fuel production and consumption in the US

According to the U.S. Energy Information Administration (2018), the total consumption of jet fuel in the U.S was 623 million barrels in 2018. The state with the highest consumption was California at 121 million barrels, while West Virginia consumed only 217,000 barrels. For context, the jet fuel consumption of Norway was 7.5 million barrels. Commercial flights within and from the U.S. resulted in approximately 220 million tons of carbon dioxide emissions. This is roughly equivalent to the total national emissions of Argentina or Vietnam. The U.S. Environmental Protection Agency has set a goal for 1 billion gallons of renewable jet fuel to be consumed annually, starting in 2018. This represents approximately 6 percent of total consumption (U.S. Environmental Protection Agency, 2020).

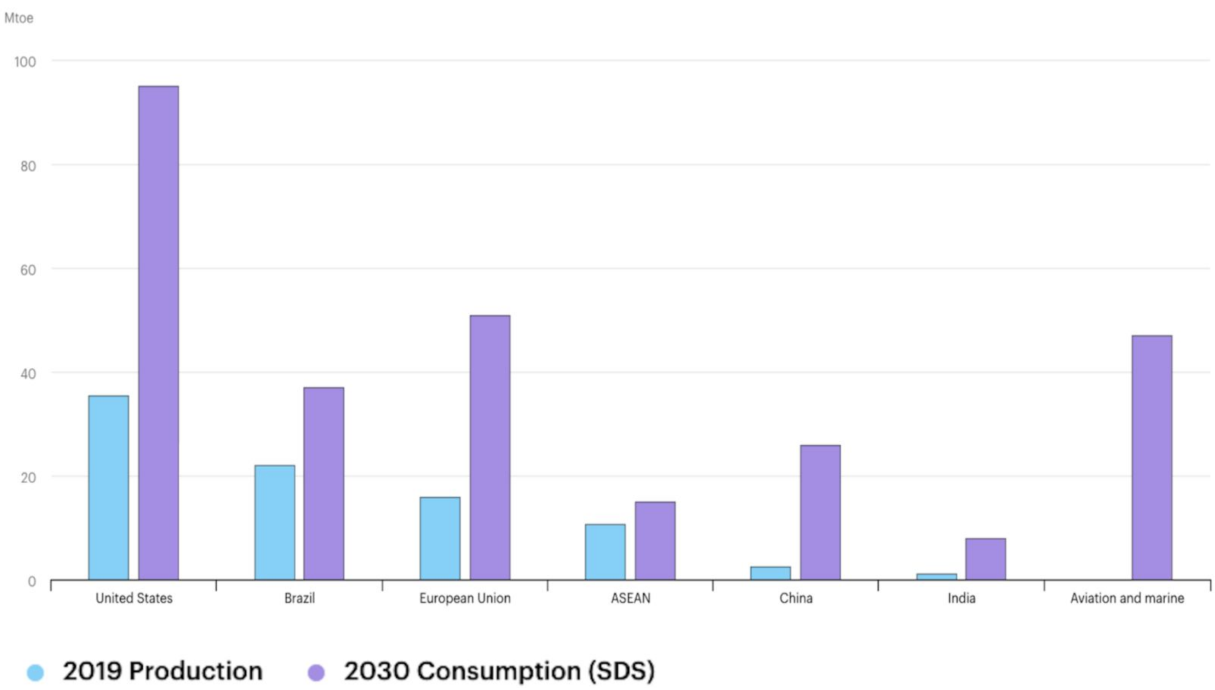
An important consideration in evaluating the market and environmental potential of drop-in biofuels is the "economic inertia" that keeps older and less efficient aircraft in use. The median life span of commercial aircraft in the U.S. is 30 years (Average Age of Aircraft, n.d.). Accordingly, efficiency improvements from new aircraft take an extended period to be reflected in actual fuel savings relative to the more immediate savings offered by low-carbon drop-in fuels.

Another challenge facing low-carbon drop-in fuels is production. The IEA, in its Sustainable Development Scenario (SDS), estimates that low-carbon fuels will meet 9% of aviation fuel demand by 2030. This assumes a sustained annual growth in biofuels production of 10%. While production grew by 6% in 2019 to 161 billion liters, an average output growth of 3% is expected for the next five years. All these are forecasts done before the COVID-19 pandemic (Teter et al., 2019).

Stronger policy support and innovation to reduce costs are necessary in order to significantly scale-up both the adoption of biofuels and their consumption in aviation and as envisaged in the SDS. As only those biofuels that are truly sustainable have a place in the SDS, more widespread sustainability governance must occur concurrently with increased biofuel output (Teter et al., 2019).

Figure 10

Biofuel production in 2019 compared to consumption in 2030 under the Sustainable Development Scenario in Mtoe.



Note. From "Tracking Transport Report", by IEA, 2019. (https://www.iea.org/reports/tracking-transport-2019).

2.4 Market potential and possibilities

Recent estimates are that the U.S. airline industry acts as a catalyst of $1.7 trillion USD in economic activity (Airlines for America, 2020). The financial health or lack thereof of airlines has a ripple-effect through the rest of the economy. As of late 2016 when West

Texas Intermediate crude oil (WTI) was at $55 USD per barrel, fuel accounted for 27% of airline operating expenses. Accordingly, it is essential to take fuel cost considerations into account when evaluating alternative fuels.

An important consideration in evaluating the market and environmental potential of drop-in biofuels is the "economic inertia" that keeps older and less efficient aircraft in use. The median life span of commercial aircraft in the U.S. is 30 years (Average Age of Aircraft, n.d.). Accordingly, efficiency improvements from new aircraft take an extended period to be reflected in actual fuel savings relative to the more immediate savings offered by low-carbon drop-in fuels.

The cost of low-carbon drop-in fuels varies widely and is dependent in part on feedstock, method of production and scale. (U.S. Department of Energy, 2017). Results of a multitude of academic studies indicate that most alternative jet fuels range in price from $2-10 USD per gallon[1] (Wang et al., 2016). This compares to a current nationwide JET-A retail price of $4.05 per gallon measured at 3,660 nationwide fixed-base operators, known as FBO (AirNav, 2020). This demonstrates that even in the current low-oil price environment it is possible in general terms for alternative jet fuels to compete with fossil-based JET A on the basis of price, particularly with the addition of modest passenger-paid fuel surcharges as evaluated in the survey component of this thesis.

Those low-carbon aviation fuels that are based on an organic feedstock are subject to limitations in terms of the land and resources necessary to grow the relevant feedstock. As a result of the magnitude of U.S. jet fuel consumption (approximately 50 million gallons per day), any alternative is likely to require significant resource inputs. There are important distinctions however between different low-carbon liquid fuel technologies in terms of the exact magnitude of resource inputs.

The presence of government support or subsidy for alternative and low-carbon fuels is subject to substantial risk from the highly variable political climate and policy environment in the U.S. While the Trump Administration's decision to withdraw the U.S. from the Paris Climate Agreement has limited direct impact on emissions due to the ability of state governments and private utilities to set their own targets, it is a symbolic measure of

[1] One U.S. gallon is equivalent to 3.778 liters.

the fragility of federal support toward the concept of climate change mitigation. This uncertainty is a significant challenge for the entire clean energy sector (Selby, 2019). This includes those companies involved in working towards low-carbon drop-in fuels in commercial aviation. A governmental system characterized by rather broad executive authority and in combination with a highly uncertain outcome of the presidential election upcoming in November of 2020 has the potential to dramatically alter national policy and the level of commitment to emissions reduction.

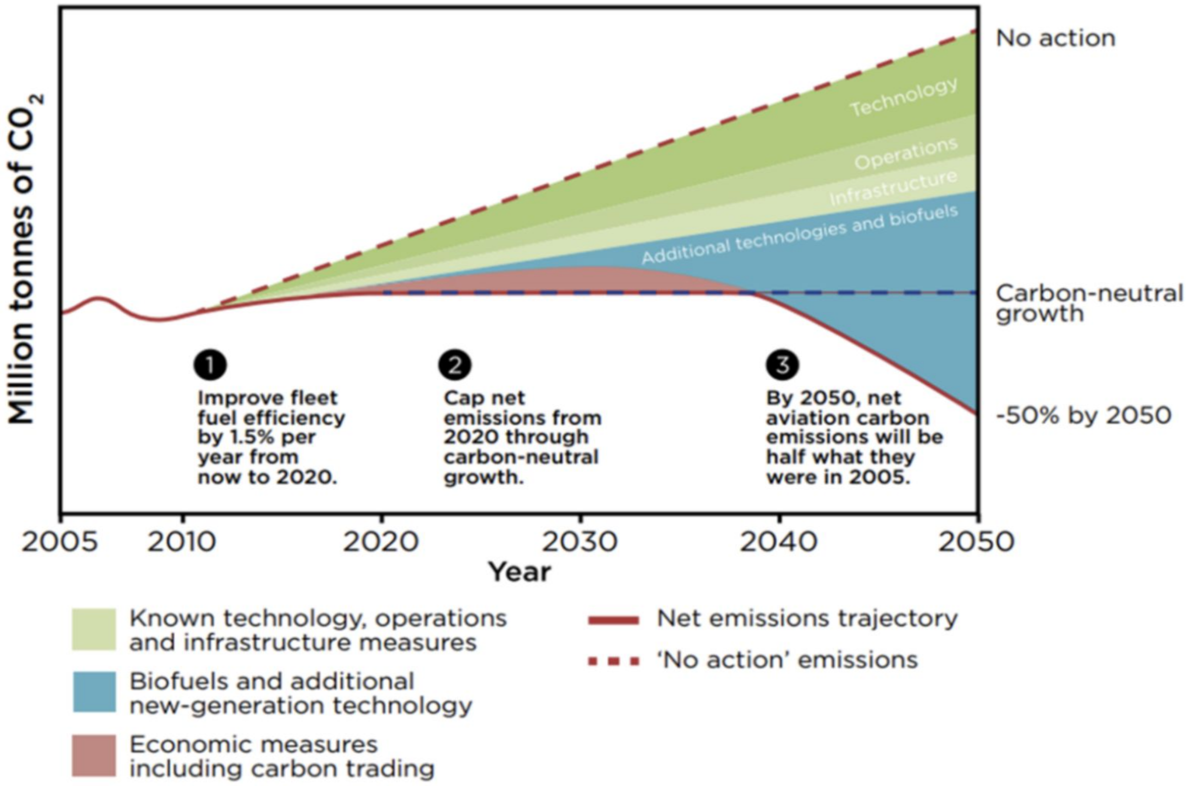
This is in part due to the fact that the public consensus surrounding anthropogenic climate change as a global threat is not universal. According to a 2019 survey, 23 percent of U.S. adults considered climate change to be only a “minor problem” or “not a problem at all” while 38 percent considered it to be a crisis (Dennis et al., 2019). This polarization is reflected in the political landscape as well. President Trump has repeatedly expressed skepticism as to the magnitude of the threat posed by CO_2 emissions and the necessity of significant emissions reductions.

In light of this polarization an outcome of interest in this research is the distinctions found by income in terms of approach to low-carbon fuels. Given the positive correlation between income and individual carbon footprint it follows that means of CO_2 reduction that appeal to those with above average incomes hold promise. Accordingly, the research element of this thesis is tailored to incomes above $50,000 USD with questions to ascertain frequency of travel.

Efforts and technologies to reduce the climate impact of aviation fall into several categories. These include investments to improve airport infrastructure and to make aircraft more efficient, low-carbon fuels and market mechanisms such as carbon pricing and emissions credits. The contribution of each of these towards total potential emissions reductions can be described as “wedges” with each component having its own contribution toward cumulative emissions reductions. As shown in the figure below the IATA considers low-carbon fuels to be essential in order for the commercial aviation industry to achieve its objectives of carbon neutral growth. This role is projected to increase over the course of the next several decades from minimal in 2020 to the largest “wedge” after 2040.

Figure 11

IATA's schematic CO2 emissions reduction roadmap.



Note. Adapted from "Aircraft Technology Roadmap to 2050", by IATA, 2020 (https://www.iata.org/contentassets/8d19e716636a47c184e7221c77563c93/technology20roadmap20to20205020no20foreword.pdf).

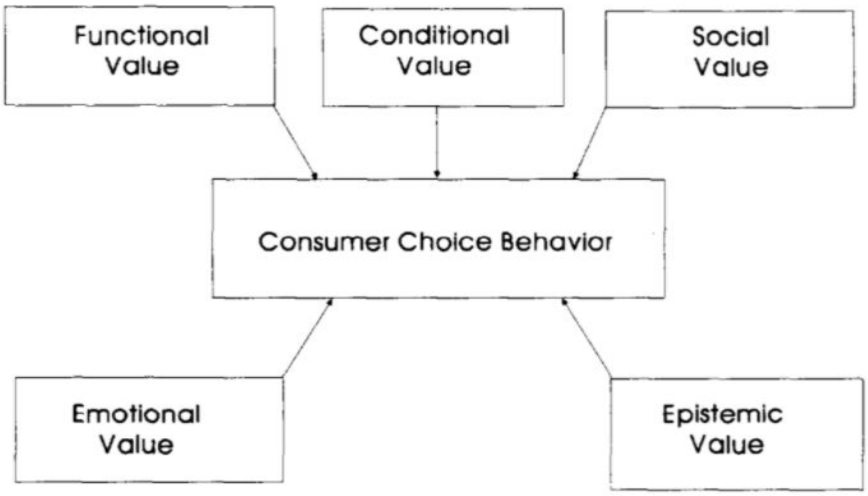
Chapter 3: Theoretical Foundations & Application

3.1 Theory of Consumption Values

The Theory of Consumption Values is instructive in evaluating the research question of whether being presented with information about the environmental benefits of low-carbon drop-in fuels increases consumer willingness to pay for flights operated on those fuels. This theory, as described by Zailani et al. (2019) and Sheth et al. (1991) has five core elements, which can be seen in *Figure 12*.

Figure 12

The five values influencing consumer choices.



Note. From "Why we buy what we buy: A theory of consumption values", by Sheth et al., 1991, *Journal of business research,* *22*(2), p.160. (https://doi.org/10.1016/0148-2963(91)90050-8).

The five elements contributing to consumer choice behavior in relation to new products are: Functional Value, Conditional Value, Social Value, Emotional Value, and Epistemic Value. In the context of low-carbon fuels in aviation these elements come into focus as follows on pages 36-37 below:

Functional value

A core feature of low-carbon aviation fuel is that it is functionally identical to standard jet fuel with the exception of the GHG emissions associated with its use. In this sense, from the consumer perspective, the differential between fuel choices is limited primarily to the way in which the fuel used affects the price of a ticket.

Emotional Value

Emotional value refers to "the perceived utility that results from a product or service that provokes feelings or affective states" (Zailani et al., 2019, p.4). Emotional value relates to low-caron aviation fuels in the sense that there is an emotional impact associated with decisions that consumers make regarding their effect on the environment. Aviation consumers have theoretical potential to derive emotional value from the satisfaction that comes with having made a choice that lessens their impact on the environment (Zailani et al., 2019).

Epistemic Value

Zailani et al. (2019) define epistemic value as "the perceived utility acquired from an alternative's capacity to arouse curiosity, provide novelty and/or satisfy a desire for knowledge" (p.5). In the context of low-carbon drop-in fuels, this value creates the link "awareness-knowledge", where the willingness to pay of consumers will be influenced by the knowledge of consumers towards the technology. By presenting consumers with meaningful information about the attributes of low-carbon drop-in fuels airlines can provide passengers with epistemic value.

Social Value

Social value is the apparent utility that results from a product's association with a social group whether demographic, cultural or socioeconomic. Previous research has shown a positive relationship between social value and sustainable consumption behaviours (Sheth et al., 1991). Accordingly and in relation to low-carbon aviation fuels, the extent to which consumers feel social value resulting from their decision to support low-carbon fuels influences the extent to which they are willing to pay to make that choice. Interrelated with this is the concept of virtue signaling. Virtue signaling is the process by which consumers actively signal their environmentally sustainable behavior to others and gain social credit as a result.

This value is in relation to improvement of the self-image and approval which affects a consumer's behaviour in relation to the natural environment and their emissions footprint. Within aviation, potential exists for airlines to tap into this concept through branding, specifically a brand extension consisting of a route or selection of routes operated exclusively with low-carbon fuels however this concept was not specifically evaluated in the course of this research.

Conditional Value

Conditional Value can be defined as the perceived utility acquired by an alternative as the result of the specific situation or set of circumstances facing the consumer. In relation to this study, participants obtain and express conditional value with their choice to pay an increased fare for a flight operated on low-carbon fuels. The information presented in the study survey about the GHG footprint of commercial aviation is part of the conditioning process (Sheth et al., 1991). Within this study, willingness to pay for a hypothetical flight is measured in a pre/post format before and after study participants are conditioned with information about low-carbon drop-in fuels.

3.2 Mere Exposure Effect Theory

In addition to the Theory of Consumption Values, an additional theory with relevance in relation to this study is the Mere Exposure Effect theory which sets forth that individuals are predisposed toward a more favorable view of that to which they have been repeatedly exposed (Yagi & Inoue, 2018). Accordingly, an essential first step toward increasing favorability toward low-carbon drop-in fuels is to provide, through visual methods, consistent exposure to the concept. Whether through their websites or through elements of the airport and onboard experience airlines have myriad opportunities to provide this exposure.

Contemporary research indicates that passenger awareness of the climate impact of aviation is increasing, reaching a level where changes in behavior are considered (Higham & Cohen, 2011). It is further true that the environmental benefits of low-carbon drop-in fuels can serve as the primary USP from the point of view of commercial aviation consumers. The environmental (GHG reduction) benefits of low-carbon drop-in fuels are the driving force behind efforts to utilize these fuels as there is no pressing shortage of oil based hydrocarbons at the present time (IEA, 2020).

Passengers on commercial aircraft and in airports represent a captive audience. This fact presents a unique opportunity to present novel information, including about the utilization of low-carbon drop-in fuels. Further, research suggests that self-described frequent-fliers are more likely to consider new products or services than the average adult (Business Wire, 2012). Airlines have a multitude of avenues with which to present information about their respective commitments to low-carbon drop-in fuels as part of the passenger experience onboard. Among the most straightforward and low-cost is through printed content placed in the seat-back pocket however the degree to which passengers read and synthesize this information is uncertain. It is incumbent on airlines to ensure that the information presented to passengers about commitments to low-carbon fuels is presented in a manner that is engaging and memorable.

There is also potential for airlines to drive awareness of low-carbon drop-in fuels through onboard in-flight entertainment systems. The captive-audience environment onboard can allow for greater recall of information and represents an opportunity for airlines to showcase their commitment to low-carbon fuels as part of the “welcome message” that typically occurs at the beginning of flights (Business Wire, 2012). By presenting information to customers in a setting where distractions are limited airlines have the potential to enhance recall and cement the association in the minds of consumers between their brands and sustainable aviation through low-carbon fuels.

3.3 Theory of Reasoned Action

The Theory of Reasoned Action as defined by Fishbein & Ajzen (1975) states that individuals consider the consequences of alternative behaviors before they engage in them, and that they then select those behaviors associated with a desirable outcome. In the model, behaviors are determined by a person's behavioral intent. Fishbein and Ajzen suggest that behavioral intent is derived from two factors: first, attitude toward the behavior, and second, subjective norms and perception of social pressure related to the behavior. In the context of this study of low-carbon fuels in aviation, the extent to which consumers have a favorable attitude toward the concept and the degree to which they perceive social pressure related to their environmental footprint can be expected to strongly influence their behavior. It is the conclusion of some contemporary research that persuasive marketing efforts should prioritise enhancement of consumer knowledge through information-based campaigns that will lead first to greater cognition and then to stronger beliefs about the salient consequences of using low-carbon energy (Bang et al., 2000).

Other studies in recent years have confirmed that both subjective norms and consumers’ perception of effectiveness at meeting environmental goals are important predictors of both biofuel purchase intention and actual biofuel purchase (Descubes, 2012). While aviation consumers are not actively making fuel purchase decisions for airlines they retain substantial indirect influence through their ability to choose to patronize airlines that commit to low-carbon fuels.

The optional surcharge to the price of a ticket as described to survey participants would ordinarily be viewed as a financial loss but through emphasis on the positive externalities (environmental benefits of the low-carbon drop-in fuels can be reframed as a gain in the minds of the passenger. Framing behaviors to mitigate climate impact as benefits rather than as sacrifices has been demonstrated in prior research to produce greater engagement and stronger behavioral intention (Gifford and Comeau, 2011).

Filimonau et al. (2018) evaluated through their research the specific public attitudes towards biofuels in aviation. They concluded that "while the potential of biofuels as a generic carbon abatement instrument was well recognized, public awareness of its specific use in the air travel sector was low. Likewise, there was limited understanding of the challenges attributed to the adoption of biofuel technology in aviation, while the desire for having more information to rectify this gap in public knowledge was recorded" (p.3108).

This presents an opportunity for airlines, through marketing initiatives, to improve consumer awareness and perception of biofuels to take the leading role in enhancing their utilization. At present, the extent to which health concerns from the evolving Coronavirus epidemic may affect consumers' ability to consider the environmental impact of their travel decisions. An additional factor enhancing uncertainty is the fact that restrictions on non-essential travel are not consistent between states such that the level of disruption to consumers is highly variable.

At present companies both within the aviation industry and beyond are conscious that the consequences of their marketing decisions can have far-reaching societal impacts. Accordingly, companies that orient themselves toward sustainable marketing consider both the social dimension and the environmental aspects of the relationship between the company, the marketplace and society (Calvo-Porral, 2019). It is then evident that the best marketing strategy is being cognizant of the long-term health of the company and the environment, while serving the needs of the market, which in the case of commercial aviation is the flying public.

Through building awareness of their efforts to support and utilize low-carbon drop-in fuels airlines have the potential to increase consumer favorability toward their brand by being perceived as a more sustainable or “green” company (Hartmann et al. 2005). As demonstrated by the survey findings of increased consumer willingness to pay for a ticket operated on low-carbon drop-in fuels, airlines have the potential to boost their revenues by adopting these fuels in their fleets. Considering that these fuel technologies are still very much in an emerging stage in the marketplace, those airlines that move first to utilize them and publicize that use can benefit from a form of first-mover advantage. First-mover advantage is defined as the market advantage reaped by companies that are first among their competitors to move into an emerging area of the marketplace (Kerin et al., 1992).

Airlines have the potential to differentiate themselves from their competitors through demonstrating a commitment to reducing their environmental impact through utilization of low-carbon drop-in fuels. To the extent that airlines are in and of themselves brands, it is well established that, when given the opportunity, consumers prefer to patronize brands with strong environmental reputations (IBM-National Retail Federation, 2020). Considering that the marketplace for commercial flights is characterized by strong competition and a plethora of choice (Wolla & Backus, 2018) airlines that demonstrate strong environmental commitments, including through the use of low-carbon drop-in fuels, have the potential to reap significant economic rewards.

3.4 SHIFT Framework

White et al. (2019) suggest typical consumer decision making theory, which mainly focuses on “maximizing immediate benefits for the self” (p.24), does not suffice to study sustainable choices of consumers. Thus, the authors argue that marketers need a unique set of tools to promote sustainability. This being a result of the fact that “sustainable choices involve longer-term benefits to other people and the natural world” (p.24). In pursuit of addressing these needs the authors developed a framework they refer to as the SHIFT framework. The SHIFT framework is an approach toward shifting consumers toward purchase behaviors that emphasize environmental sustainability. This framework includes

Social influence, Habit formation, consideration of the Individual self, Feelings and Tangibility.

In the context of consumers' willingness to pay a surcharge for low-carbon aviation fuels there is limited opportunity for social influence due to the generally private and highly individual nature of air travel purchases which primarily take place online. Habit formation has the potential to play a role if airlines were to subtly incentivise the decision to pay a low-carbon fuel surcharge through coordination with frequent flier programs though a hypothetical "green-points" offering. Tangibility of the low-carbon drop-in fuels is enhanced through means of putting the emissions reduction benefits in context that is more relatable (i.e. putting emissions savings in terms equivalent to "the low-carbon fuel this flight is operated on will save 50 tons of CO_2, the amount released by an average automobile over 300,000 km of driving".

Spence et al. (2012) also discuss how sustainable behavior is difficult to measure, of intertemporal nature, and with benefits that remain psychologically distant for consumers. Their research proves how highlighting the serious future impacts of climate change may contribute in promoting sustainable behavior among consumers. Reczek et al. (2018) confirm how sustainability feels psychologically distant to people. The authors suggest that it is imperative to encourage an orientation towards the future among consumers to promote sustainable behavior. This action will, in turn, give consumers a more abstract mindset thus catalyzing environmentally-friendly purchase behavior.

In order for this change in behavior from a shifted-to abstract mindset to be durable. certain cognitive barriers must be overcome. Cognitive barriers to understanding sustainable benefits contribute to a present bias, referring to a natural tendency to prefer outcomes that are closer to the present when considering trade-offs between two outcomes. These cognitive barriers were not explicitly evaluated in the survey component of this study but the shift in favorability toward low-carbon aviation fuels after exposure to additional information implies that these barriers were weakened among study respondents.In the study respondents were asked to consider an economic decision regarding s voluntary fuel surcharge but the monetary aspect of that decision was de-emphasized because of previous research suggesting that hlighting economic benefits can have a negative impact on consumers' interest in sustainable product concepts, such as low-carbon aviation fuels, when they are in a more abstract (vs.concrete) mindset (Goldsmith et al, 2016).

3.5 Beyond Capital

Dr. Ernst Ulrich Von Weizsäcker and Anders Wijkman, co-presidents of the Club of Rome, in their 2018 Report to the Club of Rome *Come on!: Capitalism, Short-termism, Population and the Destruction of the Planet*, conclude that economic growth theory is outdated and therefore has to be updated. The authors argue that there are limits to growth constrained by planetary boundaries, which now are more evident and palpable than ever and when the idea was first introduced in 1972, in the Club of Rome's very first report *The Limits to Growth* (Meadows et al., 1972). The authors maintain that economic growth theory assumes an *empty world*. By empty world, they refer to a time during the European Enlightenment in the eighteenth century, when the population was small, and the bounty of natural resources on the Earth seemed endless. However, this empty world changed in the mid-twentieth century, where the empty world became a *full world*. That is, a population that increased from one billion in the eighteenth century to 7.6 billion in 2018, and an ever-increasing consumption of energy, water, space, and minerals, where "growth may no longer be automatically related to living better lives, but can actually be detrimental" (p.10).

Von Weizsäcker & Wijkman (2018) emphasize that in today's *full world*, "nearly all trends of resource consumption, climate change, biodiversity losses, and soil degradation reflect the inadequacy and misdirection of public policies, business strategies, and the underlying social value" (p.11). For this reason, the authors call for a *New Enlightenment* that will question, assess, and evaluate current technologies, incentives, and rules governing all of the values, habits, regulations, and institutions of society. Contemporary economic growth theory thus has to be adapted to the conditions of a full world.

In the authors' words, "it is insufficient to incorporate environmental and social concerns by translating them into monetary expressions of capital. Nor is it sufficient to simply refer to various forms of pollution and ecosystem decline as 'externalities' – the notion being that what is at stake is some marginal disturbance" (p.11). It is along this line of thought that this research was carried out, concentrating on identifying the current public awareness of a specific target audience, and limiting the consideration of the impact of "monetary expressions of capital" in the favorability and adoption of aviation biofuels, to general macroeconomic forces shaping the aviation industry and spending behaviors of individuals, namely on airline tickets or any other expense reducing their personal income.

Chapter 4: Methods

4.1 Research Strategy and Data Collection

The original research strategy for this study required modification due to the social-distancing mandates related to the global COVID-19 situation. An in-person interview research component in frequent-flier lounges at major U.S. airports including San Francisco, Los Angeles and Las Vegas was contemplated but ultimately proved to be not feasible within the timeframe envisioned for completion.

The main objective of the research strategy as carried forward was to evaluate the public awareness and favorability of individuals towards low-carbon drop-in fuels. For this purpose, an internet-based survey was carried out in SurveyMonkey® and sent out to a tailored target audience. This group consisted of an age and location balanced cohort consisting of those with an income that exceeds $50,000 USD with questions evaluating frequency of flight and participation or lack thereof in frequent-flier programs.

Rice et al. (2017) investigated the advantages and disadvantages of internet-based survey methods in aviation-related research. The authors concluded that while internet-based surveys have some disadvantages such as lower response rates, unrepresentative samples, limited access, and lack of follow-up data, they provide an array of positive benefits and advantages for the aviation researcher.

According to Rice et al. (2017), internet-based surveys facilitate the access to new populations, benefit from larger sample sizes, allow the collection of larger volumes of quality and reliable data, enable savings in time and cost, and participants take part anonymously, which in turn, means that more participants might be willing to participate. Moreover, the authors emphasize the willingness to participate in online populations associated with structured organizations such as Amazon's MTurk or SurveyMonkey®, and the quality and reliability of data. Furthermore, these resources offer an alternative to traditional laboratory settings and are particularly attractive in light of social-distancing recommendations related to COVID-19.

The quality of data is one of the most important factors influencing research not conducted in a face-to-face setting, and must be adequately addressed when utilising oldine data collection. While not every online population for data collection has been tested for data reliability, there have been several notable studies with results suggesting that the data collected on these platforms are as reliable as data which would be collected in a traditional in-person format (Berinsky et al., 2012).

With regards to the target audience for the survey, the authors elected against using university students as a subject pool in-part because of concerns about reliability of data collected when students feel pressure, whether social or academic, to respond (Elliot, Rice, Trafimov, Madson, & Hipshur, 2010). Further, we sought to utilize as diverse and relevant of a study population as possible without inadvertent biases from geographical factors or areas of study.

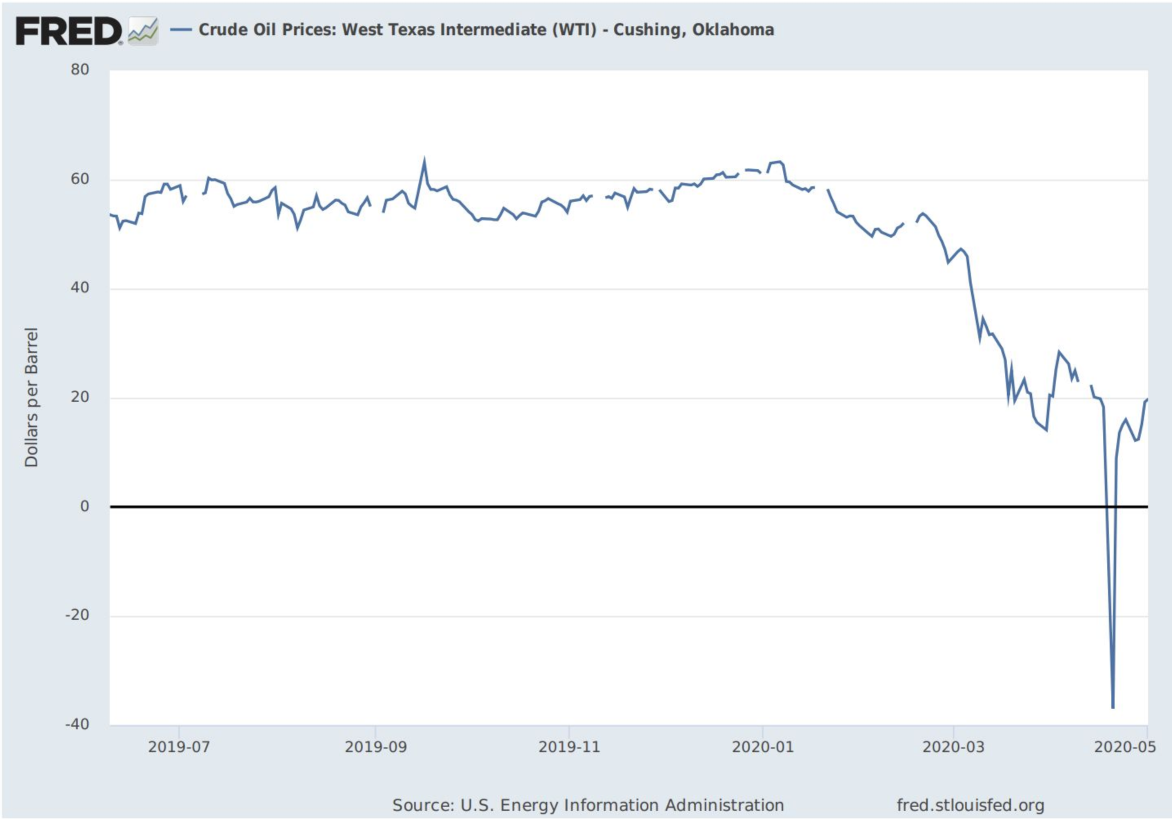
4.2 Survey Design

This research study was designed prior to the worldwide outbreak of the novel coronavirus COVID-19. Governmental responses to the virus at this point have largely been built upon a concept of "social distancing" (Centers for Disease Control and Prevention, 2020). This social distancing policy has already had a dramatic impact on the travel and tourism industries, particularly commercial aviation. Considering that the primary focus of this study is on the United States commercial aviation market and consumers of these commercial flights, the impact of COVID-19 on this study is profound. Developments unfolding daily have the potential to substantially influence the sentiments of our survey respondents.

A further unanticipated development with a material impact on the course of this research was a dramatic decline in the price of oil (and by extension jet fuel) that took place as a result of unanticipated market actions by Russia and Saudi Arabia. The breakdown of OPEC supply cuts combined with unprecedented declines in oil demand from the economic effects of social distancing caused the price of West Texas Intermediate crude to fall from above $53 USD to below $23 USD between February 23rd and March 23rd of 2020 (U.S. Energy Information Administration, 2020). This rapid ~60% decline is unprecedented and of uncertain duration as the global demand shock from COVID-19 continues to evolve. The price of jet fuel on the futures markets has followed a similarly rapid decline. *Figure 13* illustrates this recent fluctuation in crude oil prices.

Figure 13

Crude Oil Prices: West Texas Intermediate (WTI) - Cushing, Oklahoma.



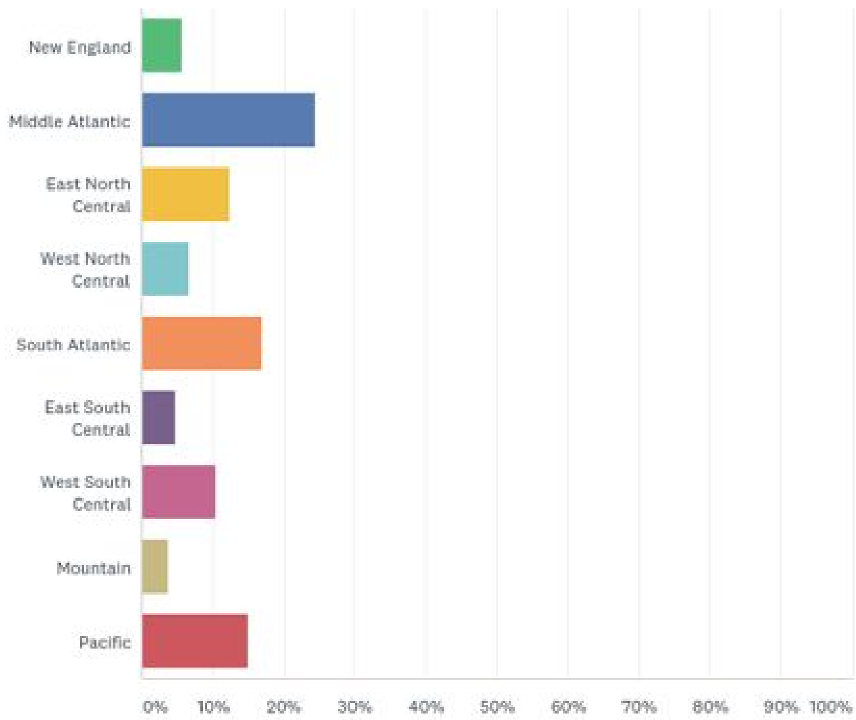
Note. From "Crude Oil Prices: WTI - FRED, Federal Reserve Bank of St. Louis", by U.S. Energy Information Administration, 2020 (https://fred.stlouisfed.org/series/DCOILWTICO).

The authors designed and conducted an online survey to determine awareness and willingness to pay (via increased airfares or an optional surcharge) for low-carbon aviation fuels. The decision to test a hypothetical surcharge is based on the fact that due in part to the current low-oil price environment it will be difficult for alternative fuels to compete on the basis of price alone. This is particularly relevant for the U.S. market where there is currently no nationwide market price placed on GHG emissions and accordingly little direct incentive for airlines to choose low-carbon fuels. The study was launched utilising the SurveyMonkey® platform with a specific target audience of 100 to 150 respondents. 133 responses were gathered with the following criteria:

- A diverse demographic profile that consists of those who have traveled by commercial aircraft once or more in the past year.
- A household income of at least 50,000 USD per year. Commercial air travel is a discretionary product. Accordingly, there is a positive correlation between income and frequency of commercial air travel (Senguttuvan, 2006). By limiting the study to those with incomes above $50,000 USD (i.e. above the median income) the authors ensured that study respondents could be considered reliable consumers.
- Comprising all regions in the United States to account for regional differences in mindset and travel habits.

Figure 14

Regional Distribution of Survey Respondents (U.S).



Note. Authors' own research.

4.3 Data Analysis and Interpretation

According to Trochim and Donnelly (2007) there are two broad methods of reasoning: inductive and deductive. The former refers to that reasoning which progresses from the more general to the more specific; the author referred to as a "top-down" approach (p.1). The latter works in an opposite manner, proceeding from the more specific to the more general, it is referred to as the "bottom up" approach (p.1). The nature of the study survey involved the utilization of both types of reasoning, however inductive reasoning is employed to a larger extent. The primary outcome measured in this study was the change in willingness to pay for a hypothetical flight operated on low-carbon drop-in fuels, itself a quantitative figure but one that served as a proxy for qualitative favorability to the fuels.

The study survey found that exposure to information about the potential environmental benefits (CO_2 reduction) of low-carbon fuels produced an increase in percentage-willingness to pay $25 USD or more per ticket by a statistically significant amount. The survey asked respondents to forecast their willingness to pay this hypothetical surcharge on a $345 USD ticket which represents the median price ticket in the U.S. (U.S. Department of Transportation, 2019).

The analysis of the data obtained from the research requires that the research approach itself was adequate and suited to the nature of the research. Bryman and Bell (2007) present two methods of data analysis: qualitative and quantitative research. Qualitative research is "a research strategy that utilizes words instead of numerical quantification in the collection and analysis of data", while quantitative research is "a research strategy that emphasizes the collection and analysis of numerical data" (p.36). The qualitative research strategy is linked to inductive reasoning, while the quantitative research strategy is associated with deductive reasoning. The nature of the research topic required that both research approaches be used in parallel. As described by Yin (2009) "mixed research methods can permit investigators to address more complicated research questions and collect a richer and stronger array of evidence than can be accomplished by any single method alone" (p.63).

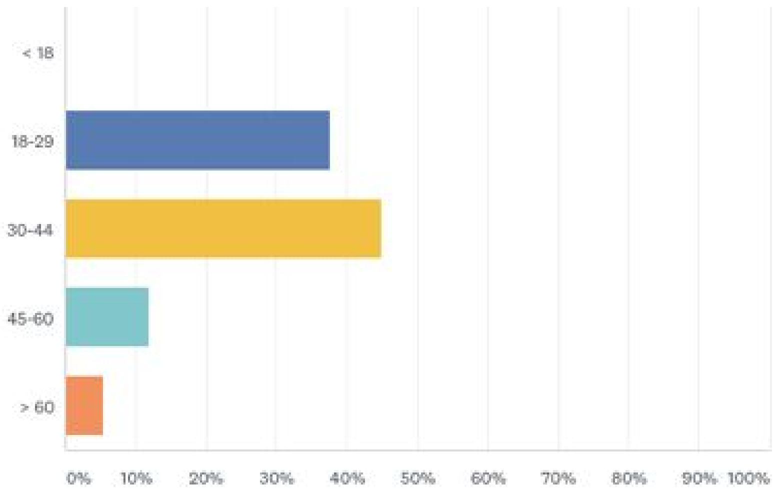
Chapter 5: Results

The authors' results indicated that the 133 survey respondents, each with incomes exceeding $50,000 USD were drawn from a diverse geographical distribution within the United States that corresponds well with the distribution of the population as a whole (see *Appendix 2*).

Figure 15 demonstrates that in terms of age, study respondents were skewed slightly younger than the U.S. population as a whole. 83 percent of respondents were under 44 years old as compared to 60.6 percent of the general population. Further, 5.5 percent of study respondents were over the age of 60 as compared to 18.5% of the U.S. population (U.S. Census, 2010). With regard to gender, 55% of study participants were male and 45% were female while the U.S. population as a whole is 49.16% male and 50.84% female per the 2010 Census data.

Figure 15

Respondents of the Low-carbon Aviation Fuel Survey by Age Group.



Note. Authors' own research.

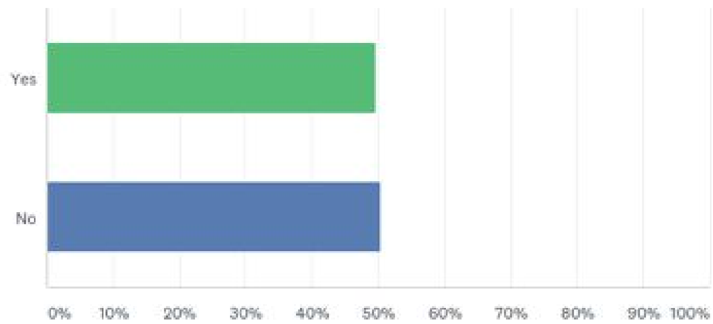
In terms of income, 89.8 % of respondents had incomes between $50,000 and $150,000 with a clear majority (60.5%) being between $50,000 and 100,000. This compares to a general population that has 31.4% of households earning between $50,000-$100,000 and 49.6% earning between $50,000 and $150,000 (U.S. Census Bureau Current Population Survey 2019).

In order to evaluate any differences in responses among those with existing loyalty to a particular airline, participants were asked whether they were members of a frequent-flier program with the results being as shown in *Figure 16*. This was intended primarily to gain further insight into the general characteristics of survey respondents and also as a secondary proxy indicator of flight frequency.

The study also measured respondent's flight frequency as a means of evaluating the general air travel characteristics of the respondents. The results showed that a plurality took two or more flights per year (measured as individual flight segments) while ~25% took 6 or more flights. The distribution of flight frequency among study respondents is shown in *Figure 17* on top of page 50.

Figure 16

Percentage of respondents that were members of a frequent-flier program.



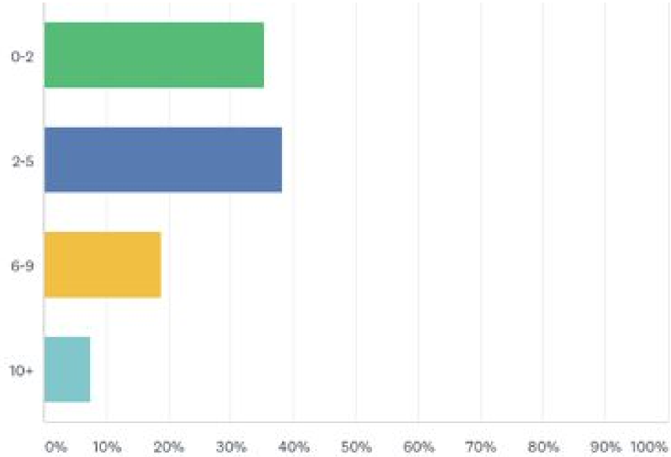
ANSWER CHOICES	RESPONSES	
Yes	49.62%	66
No	50.38%	67
TOTAL		133

Note. Authors' own research.

Figure 18, also on page 50, shows the survey results regarding willingness to pay a low-carbon fuel surcharge at baseline before exposure to detailed information about the environmental benefits of the alternative fuels.

Figure 17

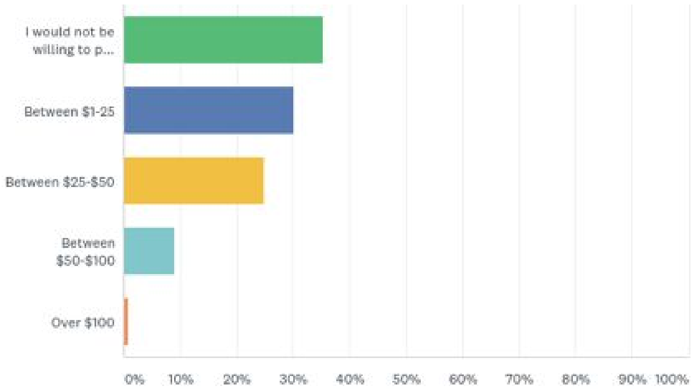
Number of commercial flights taken by respondents in a year. [2]



Note. Authors' own research.

Figure 18

Willingness to pay a ticket surcharge for a flight operated on low-carbon fuel: frequency and amount.



ANSWER CHOICES	RESPONSES	
I would not be willing to pay more	35.34%	47
Between $1-25	30.08%	40
Between $25-$50	24.81%	33
Between $50-$100	9.02%	12
Over $100	0.75%	1
TOTAL		133

Note. Authors' own research.

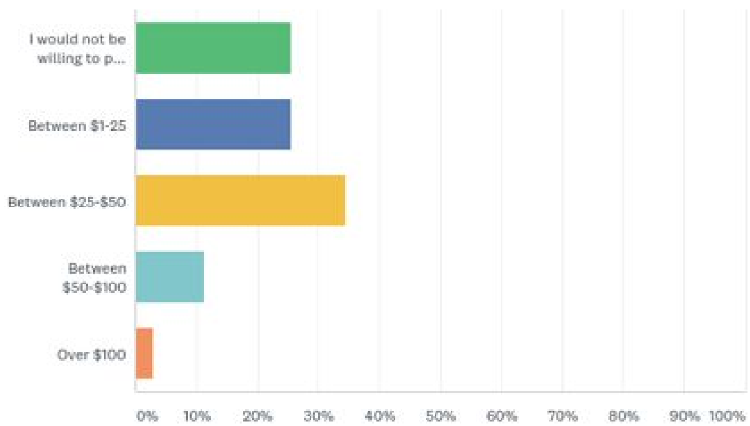
[2] Each leg (takeoff and landing) counts as a flight.

The core outcome evaluated in the study was awareness of and favorability toward low-carbon liquid fuels at baseline and after exposure to information about the emissions reduction attributes of the fuels. This was measured in terms of willingness to pay a surcharge on a hypothetical median priced airline ticket.

These results were as follows: Before exposure to the presented information 34% of participants were unwilling to pay any extra amount for a flight operated on low-carbon liquid fuels.After exposure the percentage unwilling to pay any additional amount decreased to 25% as shown in *Figure 19* below. The specific dollar amount of surcharge passengers were willing to pay for a flight operated on low-carbon fuels also increased after exposure to the tailored infographic. Before exposure, ~34% of respondents were willing to pay a $25 USD or larger surcharge while this percentage increased to 48% after exposure. This result passed an *a* .05 test of statistical significance with a power of 92.38% and a p-value of .0085 at a 95% CI, thus rejecting a null hypothesis regarding this core study result.

Figure 19

Willingness to pay a ticket surcharge for a flight operated on low-carbon fuel: frequency and amount after information exposure.



ANSWER CHOICES	RESPONSES	
I would not be willing to pay more	25.56%	34
Between $1-25	25.56%	34
Between $25-$50	34.59%	46
Between $50-$100	11.28%	15
Over $100	3.01%	4
TOTAL		133

Note. Authors' own research.

Chapter 6: Discussion & Conclusions

6.1 Discussion

A benefit of the online study design with participants that were physically remote and unknown to each-other avoiding risks from social pressure or influence. The survey respondents were also selected by a means that avoided biases inherent to the social networks of the authors and any influences that these could potentially have on the results.

Our survey began with a question intended to measure baseline awareness of low-carbon drop in fuels among survey respondents. The study was designed such that respondents must have an annual income in excess of $50,000 USD. This criteria was intended to ensure that survey respondents were reasonably likely to be consistent users of commercial air travel. This is due to the well-established positive correlation between income and travel habits. 39.45% of respondents had an income in excess of $100,000 USD compared to 30.5% of the population as a whole.

Given that ~45% of respondents were between ages of 30-44 the "young professional" demographic was strongly represented among the study audience. while 37.6% were 18-29. In total, 82% were under age 44 in comparison to 36.5% of the U.S. population as a whole belonging to this group. This survey audience has characteristics that indicate present and future spending power such that their preferences will have a material impact on the future of air travel.

As the United States market was the focal point of the research study it is fitting that 85% of respondents indicated that the U.S. was either the origin or the destination of the majority of their flights. The overall characteristics of the study respondents are such that it is evident that commercial aviation is a material part of their habits and lifestyle with approximately 50% being members of a frequent-flier program. Due to an intent to evaluate individual attitudes without influence from external factors, all respondents were individuals and corporate entities were not surveyed within the scope of this study.

Study results indicated that after being presented with information about low-carbon drop-in fuels, willingness to pay more for a ticket on a flight operated with those fuels increased materially. This serves as a demonstration of the concepts underlying the Mere Exposure Effect Theory wherein repeated exposure increases favorability. As the design of this study was such that respondents were presented with the infographic about low-carbon drop-in fuels only once, the role of the Mere Exposure Effect is limited primarily to the 58.65% of respondents that had some conceptual awareness of low-carbon drop-in fuels at baseline.

Respondents were asked twice about their willingness to pay a ticket surcharge for a flight operated on low-carbon fuel twice, the second time after having been exposed to information about the environmental attributes of the fuels. This being demonstrated through the positive correlation between the presentation to passengers of detailed and contextualized information about low-carbon drop-in fuels and their subsequent willingness to pay for those fuels.

This demonstrated that study participants were broadly receptive to the information presented in the study as indicated by an increased willingness to pay post-exposure (see *Appendix 1*, question 7). Specifically, cumulative willingness to pay a surcharge of $25 or more increased from 34.6% to 48.9%. A subset (3% of respondents indicated a dramatic response to the information presented about low-carbon drop-in fuels such that they were willing to pay more than $100 USD more for a flight operated on these fuels after exposure.

These results suggest that the social cost and negative externality of CO_2 emissions resonated strongly with study participants. The clear and evident impact of the information presented about low-carbon drop-in fuels on favorability and willingness to pay was a satisfactory result that demonstrated the effectiveness of the infographic within the study.

The optional fuel surcharge incorporated in the study and survey respondents willingness to pay the surcharge demonstrated the application of concepts described previously in the Theory of Reasoned Action. Specifically, the introduction of information about the attributes of low-carbon drop-in fuels was able to generate a more positive attitude toward these fuels thereby increasing respondents' behavioral intention toward paying the fuel surcharge. This was evidenced by the percentage willing to pay a surcharge increasing from 34.6% to 48.9% as noted above. The willingness to pay for a flight ticket increased once the respondents' awareness of low-carbon drop-in fuels increased. It can accordingly be stated that the sense of “financial loss”, resulting from the fuel surcharge decreased as the behavioral intent from the respondents to contribute toward the mitigation of emissions, and ultimately, climate change became stronger.

The study results demonstrated elements of the Theory of Consumption values as respondents derived *epistemic value* from the infographic presented building awareness, arousing curiosity then ultimately satisfying a desire for knowledge about low-carbon drop-in fuels. Further, the opportunity to directly impact the utilization of these fuels on their flight through the payment of an optional fuel surcharge represents a novel experience for airline customers that have traditionally been entirely unable to influence the fuel utilized for their flights. Study participants also derived *conditional value* as the GHG emissions savings from low-carbon fuels were put into specific and relatable contexts. Airlines have the potential to enhance the conditional value of customers’ decision to pay the low-carbon fuel surcharge through incorporating an incentivisation through their frequent-flier programs but such an incentive was not evaluated in this study. Due to the operational equivalency between standard JET-A and low-carbon alternatives the *functional value* of the low-carbon drop in fuels to study participants was limited to the extent to which they considered the reduction of their GHG footprint to be a desired and valued functional outcome.

As the payment of the low-carbon fuel surcharge is private and the study participants were remote from each other the *social value* of the decision to pay the surcharge is limited to the degree to which the decision enhances the participants self-image as a environmentally-conscious consumer. Social value would be potentially increased further if the option was presented to share the decision to pay the low-carbon fuel surcharge through social media platforms but that concept was not evaluated in this study.

The consumer perception of relatability surrounding low-carbon drop-in fuels was enhanced through the putting the emissions reduction benefits in a context more relatable to the flying public. To provide a sense of the scale of potential emissions reductions in a scenario of broad adoption of low-carbon drop in fuels throughout commercial aviation, these were demonstrated to be roughly equivalent to those of The Netherlands, of Scandinavia or the U.S state of New York. These comparisons assumed a general familiarity with the size of these markets and the scale of their greenhouse gas emissions.

By not emphasizing the monetary elements if the fuel-surcharge purchase decision survey respondents were shifted toward a more abstract mindset in accordance with the SHIFT framework set forth by White et al. (2019) shifting focus away from immediate monetary benefits to themselves and toward the sustainable purchase decision option of the low-carbon fuel surcharge. The clear and evident impact of the information presented about low-carbon drop-in fuels on favorability and willingness to pay as described in the context of the theories presented was a satisfactory result that demonstrated the effectiveness of the infographic within the study.

6.2 Conclusions

The results of the study demonstrated that the flying public is potentially receptive to the concept of paying increased airfares in exchange for the reduced carbon-footprint offered by low-carbon drop-in fuels. This demonstrates the potential of these fuels to gain “market share” even without needing to be fully cost-competitive with conventional JET-A. Interpretations of data from the survey are below:

Despite the fact that the research survey targeted through income a specific segment of the population for whom flying is commonplace, the baseline level of awareness of the target audience regarding low-carbon drop-in aviation fuels was low. Only 16.54 % of respondents responded “yes, very much” to a question evaluating whether they were aware of the concept before exposure to the infographic contained in the study.

Prior to being exposed to selected information, comprising the definition and material positive impact of low-carbon drop-in fuels in the environment, respondents were asked whether they would prefer a flight operated on low-carbon fuel over an equivalent flight operated on conventional fuel assuming an equivalent ticket price. The findings clearly indicate the preference and favorability of the respondents (83.5%) to low-carbon fuels. As elaborated further in the Discussion section of this study, being presented with detailed information about low-carbon fuels materially increased customer willingness to pay for a flight operated on these fuels. Among those with a baseline willingness to pay a low-carbon fuel surcharge the amount that they were willing to pay increased after exposure to additional information about the concept.

This reinforced the concept of a positive association between awareness and favorability and demonstrated the importance of airlines highlighting their commitments and investments in the low-carbon fuel space. Airlines that do not adequately educate and inform customers about their efforts to reduce emissions through the use of low-carbon liquid fuels risk missing an opportunity to earn significant additional revenues through low-carbon fuel surcharges. Those that seize the opportunity to become leaders in the space have the potential to materially reduce their GHG footprints in a way that meets the dual objectives of environmental and financial sustainability.

6.3 Suggestions for Further Research

Avenues for further research could include broadening the study beyond the United States marketplace to gain perspective into global perception of low-carbon drop-in fuels. This would be of significant utility given that the largest airlines are highly globalized entities. Additionally, it could be fruitful to study the attitudes of the large corporate entities that are responsible for a significant proportion of global air travel demand in ordinary non-COVID-19 times. The long term impacts of COVID-19 on corporate travel remain fluid and uncertain but the dramatic growth in utilization of platforms that replace in person meetings is expected by some researchers to have a long-lasting negative impact on frequency of travel.

Another area with potential for further research is the present state of feedstock limitations and the extent to which they may limit the viable production volumes of low-carbon drop-in fuels. Although detailed analysis of these factors was nor included in the scope of this study they are very likely to be relevant in any widespread adoption of low-carbon liquid aviation fuels. These limitations are likely to be subject to revision over time both due to the effects of anthropogenic climate change and ongoing technological advancements. As the end objective of any low-carbon fuel is to reduce emissions not only from combustion but from the entire lifecycle of the fuel, more research into the complete lifecycle emissions of various feedstocks will be likely necessary. This would assist in the process of determining which fuels deliver GHG emissions reductions most cost-effectively on a “price per ton” of avoided emissions basis.

Additional research could also be undertaken into the economic aspects of specific low-carbon drop-in fuels in differing oil-price environments. Traditionally, biofuels suffer when oil prices decline and the economic incentive to utilize alternatives is reduced.. The dramatic shifts in the global oil markets brought upon by the COVID-19 demand shock made accurate cost analysis difficult within the timeframe that this study was undertaken. The extent to which commercial aviation will return to “normal” conditions is unknown at the present time and will likely remain so for a considerable period of time. Current estimates are that a vaccine may be developed in a 12-18 month window (by summer of 2021) but this remains highly uncertain at the present time..

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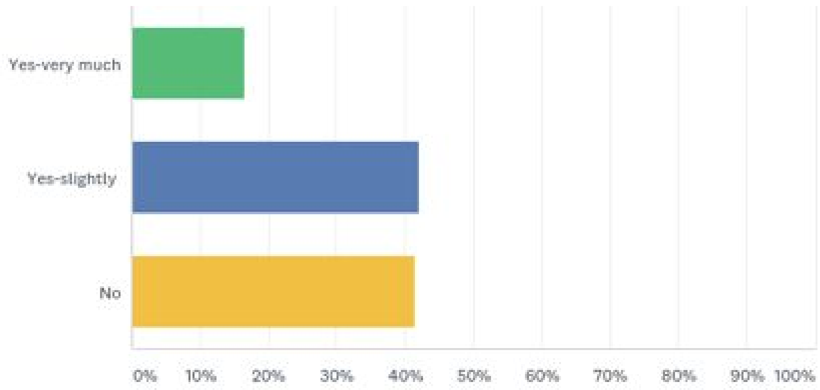
Appendices

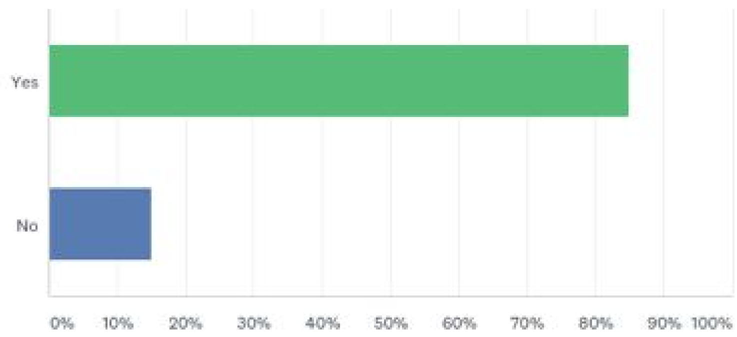
Appendix 1. Survey on low-carbon jet fuel awareness.

Q1: We are studying the market perception of low-carbon drop-in aviation fuels. Are you aware of this concept?



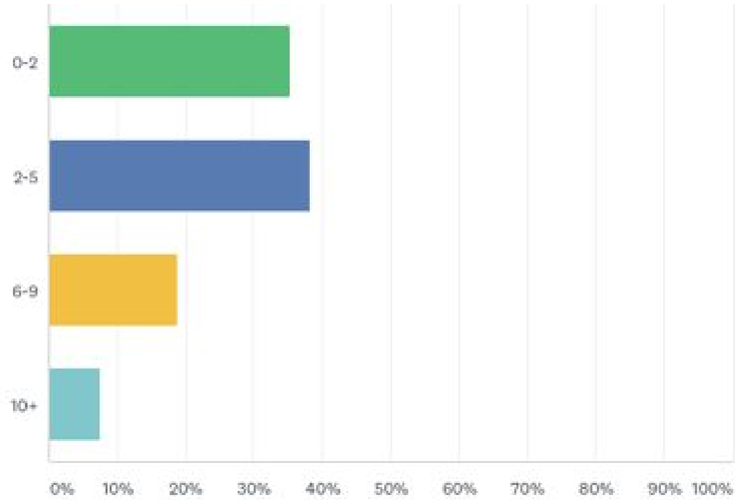
ANSWER CHOICES	RESPONSES	
Yes-very much	16.54%	22
Yes-slightly	42.11%	56
No	41.35%	55
TOTAL		133

Q2: Is the United States the origin or destination of at least 50% of the flights you take?



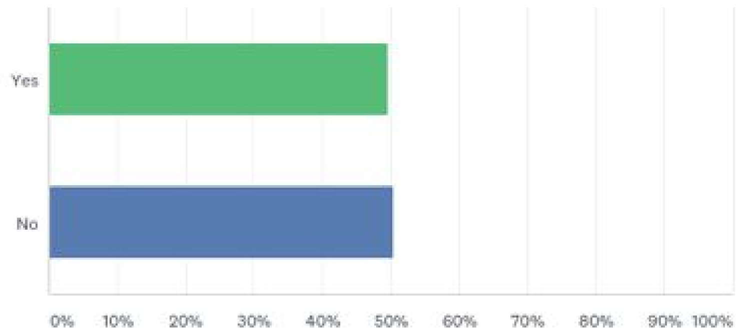
ANSWER CHOICES	RESPONSES	
Yes	84.96%	113
No	15.04%	20
TOTAL		133

Q3: How many commercial flights do you take per year? Each leg (takeoff and landing) counts as a flight.



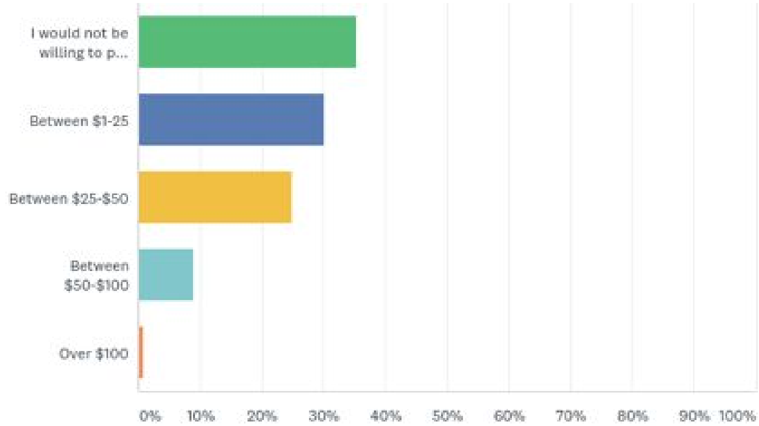
ANSWER CHOICES	RESPONSES	
0-2	35.34%	47
2-5	38.35%	51
6-9	18.80%	25
10+	7.52%	10
TOTAL		133

4: Are you a member of a frequent flier program?



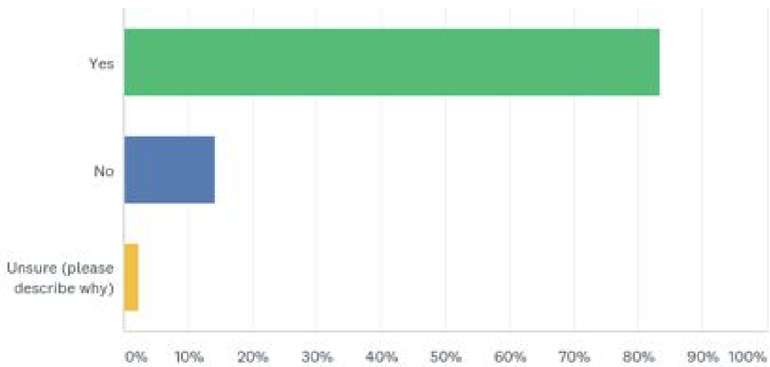
ANSWER CHOICES	RESPONSES	
Yes	49.62%	66
No	50.38%	67
TOTAL		133

Q5: According to the U.S. Department of Transportation the national average price for a round-trip domestic flight in Q3 2019 in the U.S. was 345.09 USD. Given these figures, how much more would you be willing to pay for a ticket for a flight using a low-carbon drop-in fuel?



ANSWER CHOICES	RESPONSES	
I would not be willing to pay more	35.34%	47
Between $1-25	30.08%	40
Between $25-$50	24.81%	33
Between $50-$100	9.02%	12
Over $100	0.75%	1
TOTAL		133

Q6: If there was no difference in ticket prices would you prefer a flight operated on low-carbon jet fuel over an equivalent flight operated on conventional fuel?



ANSWER CHOICES	RESPONSES	
Yes	83.46%	111
No	14.29%	19
Unsure (please describe why)	2.26%	3
TOTAL		133

Q7: Please read and carefully consider the following information before proceeding:

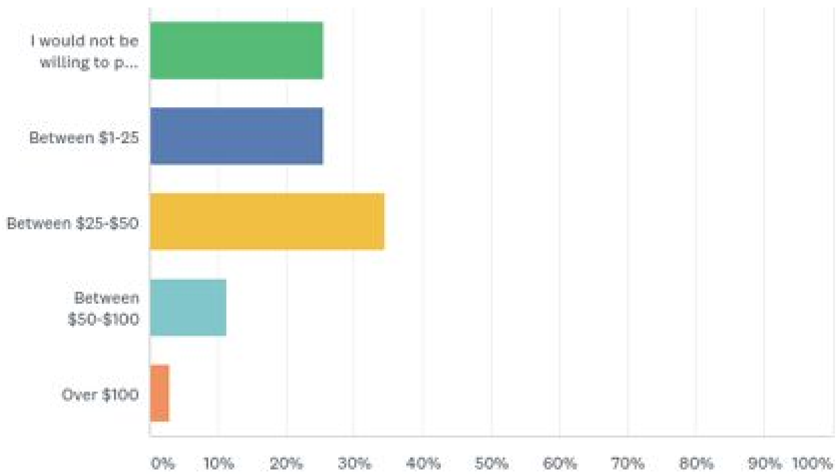
- Low-carbon drop-in fuels are liquid fuels that can deliver reduction in emissions of carbon dioxide (CO_2) and other greenhouse gasses that can be utilized in existing internal combustion engines without substantial modification.
- Low-carbon drop-in fuels deliver a reduction of CO_2 emissions of up to 80-85% compared to conventional aviation (fossil) fuels. CO_2 emissions from all commercial aviation operations in 2018 totaled 918 million metric tons—2.4% of global CO_2 emissions from fossil fuel use. Using aviation industry values, there has been a 32% increase in global aviation-related emissions over the past five years. (International Council on Clean Transportation, 2018).
- Flights departing airports in the United States and its territories emitted about one-quarter (24%) of global passenger transport-related CO_2, two-thirds of which came from domestic flights. The top five countries for passenger aviation-related carbon emissions were rounded out by China, the United Kingdom, Japan, and Germany. (International Council on Clean Transportation, 2018).

Put into perspective these figures, reducing the U.S. yearly aviation emissions by 80%, or 176 million metric tonnes of CO_2, is the equivalent to reducing more than the total yearly CO_2 emissions (from all sources) for:

- The Netherlands (162 million metric tonnes CO_2), or
- Scandinavia (170.6 million metric tonnes CO_2). **Five countries in total** with their respective emissions in million metric tonnes CO_2: Norway 44 Mt, Sweden 41 Mt, Finland 47 Mt, Denmark 35 Mt, Iceland 3.6. Mt.
- This figure is also roughly equivalent to the emissions of the State of New York (164.6 million metric tonnes CO_2).

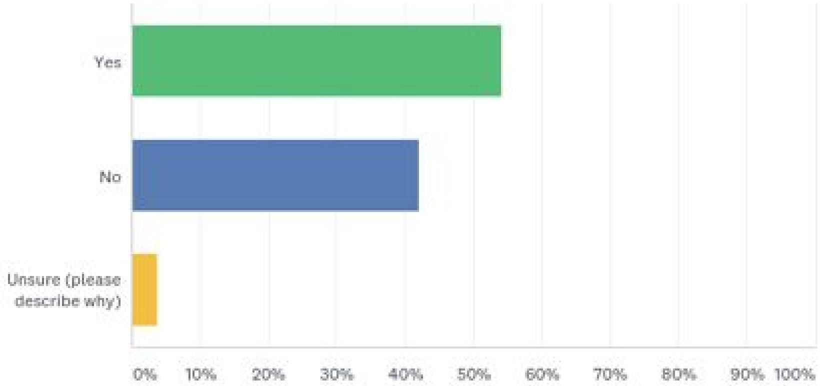
Having now presented information about the emissions reduction potential of low-carbon drop-in fuels we will now ask a previous question once again. *Please forgive the redundancy.*

According to the U.S. Department of Transportation the national average price for a round-trip domestic flight in Q3 2019 in the U.S. was 345.09 USD. Given these figures, how much more would you be willing to pay for a ticket for a flight using a low-carbon drop-in fuel?



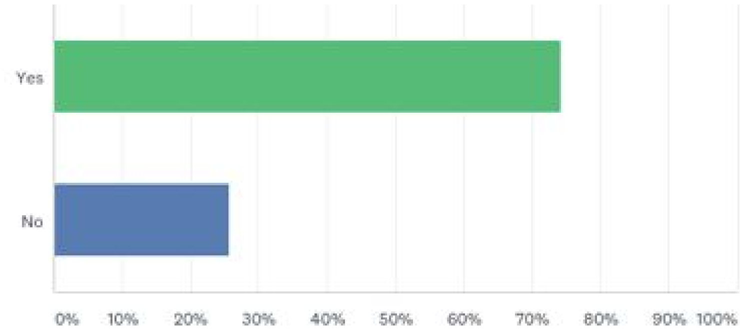
ANSWER CHOICES	RESPONSES	
I would not be willing to pay more	25.56%	34
Between $1-25	25.56%	34
Between $25-$50	34.59%	46
Between $50-$100	11.28%	15
Over $100	3.01%	4
TOTAL		133

Q8: The lockdown measures taken to combat the global Coronavirus (COVID-19) pandemic have caused air travel to plummet-has the virus changed your personal long term mindset toward air travel?



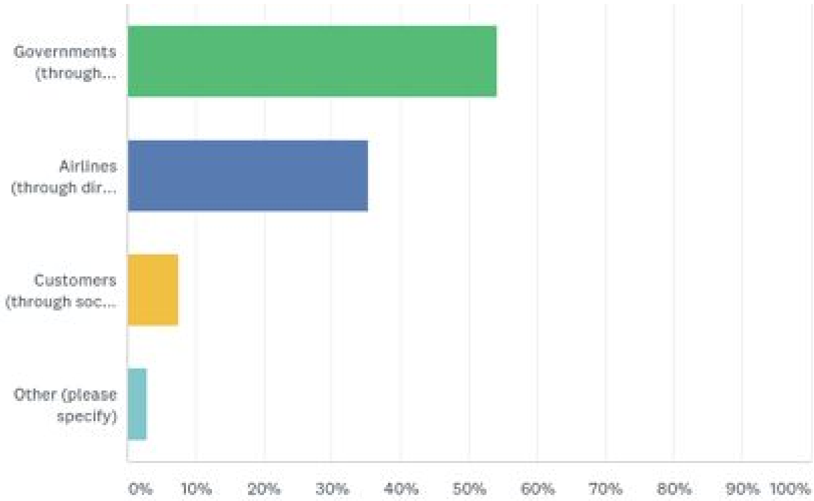
ANSWER CHOICES	RESPONSES	
Yes	54.14%	72
No	42.11%	56
Unsure (please describe why)	3.76%	5
TOTAL		133

Q9: If you were shopping online for a flight would you prefer that airlines provide information on whether the flight is operated with low-carbon fuel?



ANSWER CHOICES	RESPONSES	
Yes	74.24%	98
No	25.76%	34
TOTAL		132

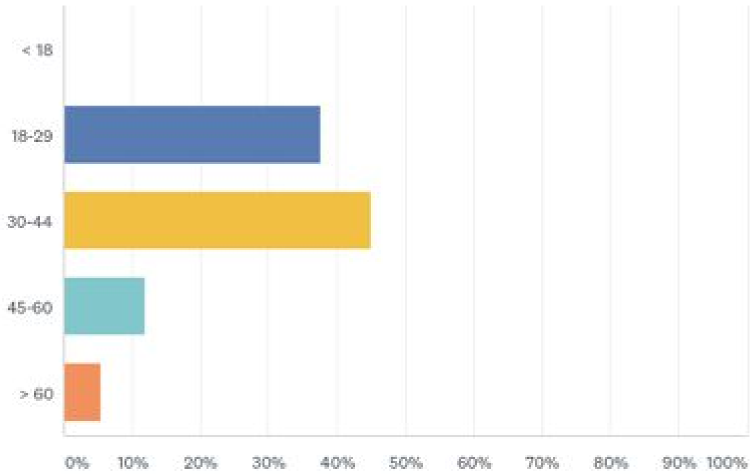
Q10: In your opinion, should efforts to increase favorability toward, and utilization of, low-carbon fuels in aviation be led by:



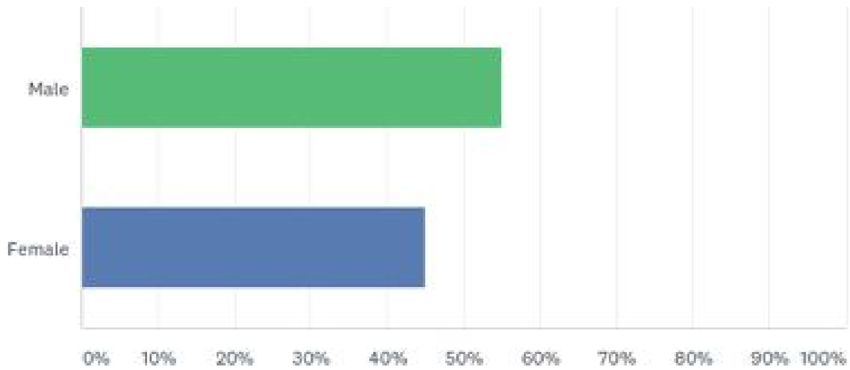
ANSWER CHOICES	RESPONSES	
Governments (through subsidy or a carbon tax)	54.14%	72
Airlines (through direct investment in fuel producers and through advertising)	35.34%	47
Customers (through social media, word-of-mouth etc.)	7.52%	10
Other (please specify)	3.01%	4
TOTAL		133

Appendix 2. Target Audience

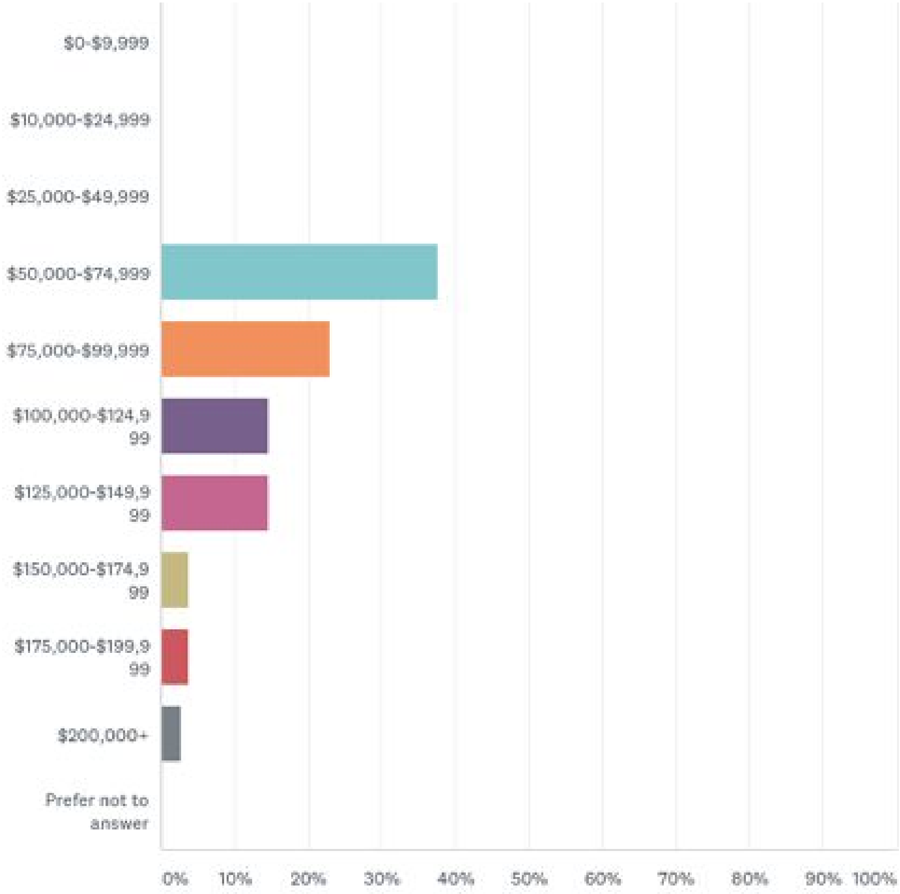
Age



Gender

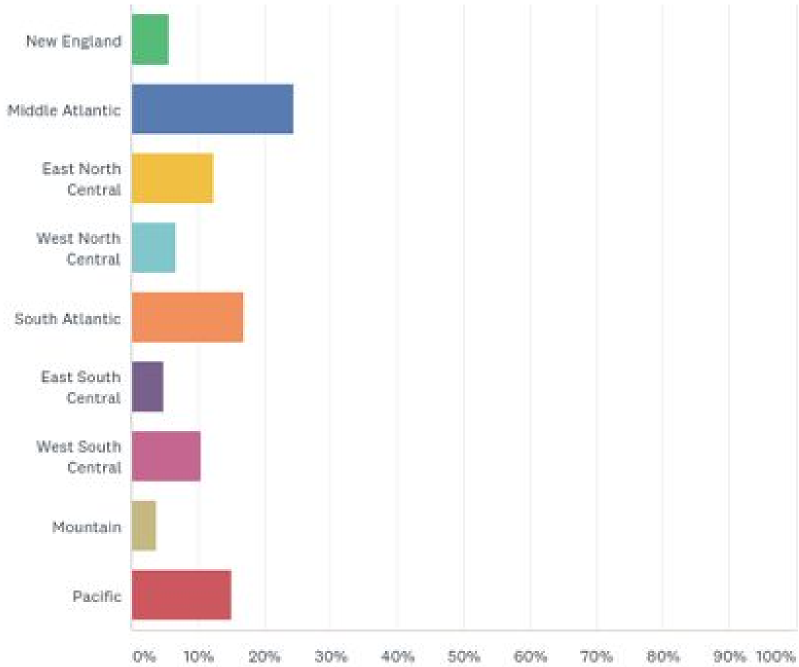


Household Income



ANSWER CHOICES	RESPONSES	
$0-$9,999	0.00%	0
$10,000-$24,999	0.00%	0
$25,000-$49,999	0.00%	0
$50,000-$74,999	37.59%	50
$75,000-$99,999	22.56%	30
$100,000-$124,999	15.04%	20
$125,000-$149,999	15.04%	20
$150,000-$174,999	3.76%	5
$175,000-$199,999	3.76%	5
$200,000+	2.26%	3
TOTAL		133

U.S. Regional Distribution Among Respondents



ANSWER CHOICES	RESPONSES	
New England	5.66%	6
Middle Atlantic	24.53%	26
East North Central	12.26%	13
West North Central	6.60%	7
South Atlantic	16.98%	18
East South Central	4.72%	5
West South Central	10.38%	11
Mountain	3.77%	4
Pacific	15.09%	16
TOTAL		106