Sustainable commercial aviation: What determines air travellers’ willingness to pay more for sustainable aviation fuel?

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A B S T R A C T

While low carbon jet fuels (LCJF) offer a viable alternative to conventional jet fuels in terms of reducing aviation emissions, the higher fuel costs may be passed on to customers in the form of increased ticket prices. However, there has been little research into the public’s willingness to pay (WTP) for LCJF use. Our study addresses this gap by exploring citizen’s perceptions of, attitudes toward, and willingness to pay a premium ticket price. We conducted an online survey among UK citizens (N = 1008) who flew at least once a year. We used ordered logistic regression to predict the factors that influence WTP for LCJF. The findings confirmed the existence of three factors that explain air travellers’ WTP: social trust, perceived risks, and attitude. Although the overall perception of the benefits of LCJF outweighs the associated risks, the level of awareness of LCJF use is rather low. Despite a favourable attitude toward LCJF use, the majority of respondents were unwilling to pay more for carbon-neutral air travel. Our research contributes to and expands the literature on the current debates about acceptance and WTP for LCJF and energy transitions. Additionally, the findings of our study encourage public and corporate managers to leverage the identified key factors to inform and structure campaigns to increase the acceptability of LCJF use.

1. Introduction

The aviation industry plays a critical role in bringing global connectivity, and social and economic prosperity (IATA, 2019). More specifically, the total economic impact of the global aviation industry reached USD 2.7 trillion in 2016, corresponding to about 3.6% of the world’s gross domestic product (GDP) (ATAG, 2018). Airlines carried around 4.3 billion commercial passengers and 58 million tonnes of freight around the world in 2018 (IATA, 2019). Despite the COVID-19 pandemic having reduced air travel by about 60% in 2020 compared to 2019, the industry is on a recovery path (e.g., an overall reduction of 15% of seats offered by airlines in 2022) (ICAO, 2022). Besides economic and social benefits, the aviation sector also faces significant challenges. The foremost of such challenges is represented by global fossil jet fuel carbon dioxide (CO₂) emissions. Though commercial aviation accounts for only 2–3% of emissions (ICAO, 2016), due to the industry’s growth outlook, carbon emissions are estimated to reach as high as 22%–30% by mid-century (Staples et al., 2018). This situation warrants a combined effort from all stakeholders to reduce the carbon intensity of the aviation sector (DFT, 2022; Singh et al., 2019).

To urgently tackle the aviation industry’s GHG emissions, we need to simultaneously explore a portfolio of options such as operations management, demand reductions, technological improvements, and alternative low-carbon fuels (Singh et al., 2019). Operationally, the

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European Union’s programme ‘Single European Sky ATM Research’ (SESAR)2 and the Next Generation Air Transportation System (Next-Gen)3 in the US are aiming to modernise air traffic management. The success of these efforts ensures airlines travel the shortest possible routes, resulting in more efficient use of the skies and emissions savings. Likewise, reducing air travel demand (Kroesen, 2013) and carbon taxing (Ryley et al., 2010) are also among the alternatives considered. Despite electrification being deemed as a feasible substitute, there seems to be an agreement among stakeholders that electric aircraft may not be commercially available until well beyond 2050 (Ahmad and Xu, 2021). Hence, for the near-to-mid-term, liquid fuels will continue to play a key role in aviation. In this context, switching from traditional carbon-intensive fossil jet fuel (i.e., Jet A or Jet A-1) to a less carbon-intensive jet fuel seems to be a viable choice for mitigating emissions in the aviation sector (Singh et al., 2019; Staples et al., 2018; Kolosz et al., 2020). The key merits of low carbon jet fuels (LCJF), also known as ‘sustainable aviation fuels (SAF)’ or ‘drop-in fuels’, include that they do not require any changes to the current aircraft fleets, saving a significant financial cost to airlines when replacing their fleet. Furthermore, LCJF do not cause any disruptions to global aviation operations, are safe, and are environmentally benign.4 In addition, commercial airlines have the added advantage of using LCJF as a valuable promotion tool for attracting customers (Daggett et al., 2008).

While technological advancements, improving operational efficiencies, and introducing policy frameworks are important in achieving aviation net-zero carbon targets, the role that the public plays cannot be overlooked. In particular, LCJF can be considerably more expensive than fossil jet fuels; hence, it becomes sensible and inevitable for airlines to pass at least part of the costs on to customers in the form of a higher ticket price. However, public familiarity and willingness to pay (WTP) for the use of LCJF in aviation and its environmental benefits remain unexplored. Our paper contributes to the general social acceptance body of knowledge by investigating the public response to WTP for LCJF use in aviation based on the Theory of Planned Behaviour (TPB) framework. In our work, we leverage both the psychometric constructs of public perception, social trust, and attitude, and the demographic characteristics.

It is crucial to understand public awareness of new technologies, as these are linked to the wider social acceptance of innovations (Chin et al., 2014). Failing to increase general awareness can lead to unwillingness to pay; this, in turn, can result in the market failure of the proposed innovation (Wegener and Kelly, 2008). Note that LCJF offers a unique case of exploring public response as the possible benefits (e.g., emission savings, fossil jet-fuel independence) and concerns (e.g., competing with food supply, health risks, ecosystem impacts) are directly related to society. The possible benefits and concerns have been widely explored for other forms of transportation, mainly the road transport sector (van de Velde et al., 2011). Although public knowledge, perceptions, and responses do not guarantee adoption, their presence is likely to result in innovation and technology failure. In some cases, this may even include resistance: environmental, such as contamination risk or intergenerational gaps to develop sustainable strategies (Essiz and Mandrik, 2022). As compared to other sustainable energy options (e.g., wind and solar), less attention has been paid to studying the public’s acceptance of low carbon fuels, both in road transportation and the aviation sector (Chin et al., 2014; Kumar and Sinha, 2022).

The social context of low carbon transportation fuels has been mainly focused on studying the stakeholders’ knowledge, perceptions, attitude, social trust, and WTP (Mamadzhanova et al., 2019; Rice et al., 2020). These components are considered to be vital and pertinent in gauging the general public’s acceptance or resistance (Rahman et al., 2017; Yaghoubi et al., 2019). To be more specific, knowledge is being aware of something either by observation, usage, or education (Halter et al., 2010). Perceptions, on the other hand, relate to extracting information from one’s experience.5 Perceptions are crucial for understanding the resultant behaviour, while attitude is the evaluation of that behaviour (Radics et al., 2015; Van Dael et al., 2017).

Likewise, social trust is the public’s confidence in various key players related to technology or innovation (Amin et al., 2017). These key players could be experts or institutions that the public relies on for information or technology. These institutions may include the government as the regulator, or policymakers, industry, and scientists. Social trust is recognised as playing a critical role in developing people’s attitude

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2 www.sesar.eu.
3 www.faa.gov.nextgen.
4 Note that LCJF can be produced in many ways using a variety of sustainable feedstocks. Each production pathway has its own technical, economic, social, and environmental characteristics. The reader is referred to Ahmad et al. (2021) for a review of different LCJF production processes.
5 For details, see ‘Principles of perceptual learning and development’ (Gibson, 1969).
to technology acceptance (Adnan et al., 2018). Finally, the consumers’ WTP is their inclination to buy sustainable fuel which is available (Sivashankar et al., 2016), as well as it reflects consumers’ potential interest in bearing the cost burden of low carbon fuel (Mamadzhanov et al., 2019).

Several authors have focused on studying public knowledge and perception of and attitude toward sustainable low-carbon fuels in the road transportation sector (e.g., Sivashankar et al., 2016). The general findings were that there is a lack of awareness of low-carbon fuels; the key concerns include the alternative fuels’ performance, availability, and higher cost of alternative fuel when compared to conventional fossil fuels, and the threat to food security posed by the increased use of alternative fuels. Another stream of literature has examined the feedstock sustainability for fuel production by exploring public’s attitudes toward the environment, input energy use, and government and policymakers in ensuring the enactment of laws and regulations (Smith et al., 2018; Yaghoubi et al., 2019). However, these studies have revealed a mix of positive and negative attitudes depending on local conditions. Hence, the findings cannot be appropriately generalised to other regions because of different socio-economic and geo-political conditions.

The aviation sector is considered one of the most difficult sectors to decarbonise (Ahmad et al., 2021). Technical solutions may take longer than anticipated to mature while, on the other hand, the attitude-behaviour conflict (Filimonau et al., 2018) prevents a voluntary reduction in air-travel demand. The ‘attitude-behaviour conditions. Hence, the findings cannot be appropriately generalised to other regions because of different socio-economic and geo-political conditions.

The aviation sector is considered one of the most difficult sectors to decarbonise (Ahmad et al., 2021). Technical solutions may take longer than anticipated to mature while, on the other hand, the attitude-behaviour conflict (Filimonau et al., 2018) prevents a voluntary reduction in air-travel demand. The ‘attitude-behaviour conflict implies that while the public recognises that modifying their air travel behaviour may significantly improve GHG emission mitigation efforts, in reality they rarely do so. Therefore, switching to less carbon-intensive fuel has become a critical venue to explore.

Interestingly, only a few studies make LCJF their focal point of inquiry. For example, the studies by Filimonau and Högström (2017), and Filimonou et al. (2018) are two pioneering studies that delved into the social acceptance of LCJF use. Both studies used the constructs of knowledge, perceptions, and attitude toward sustainable liquid (bio) fuels in aviation. Filimonau and Högström (2017) found an imperfect public understanding of sustainable liquid (bio)fuels but, that LCJF are considered a safe alternative for aviation. Likewise, Filimonou et al. (2018) echoed that there is limited understanding of sustainable aviation fuel technology, besides the public’s safety concerns about its use. They also found distrust among the public in national-level institutions and, as a result, called for developing awareness campaigns to address this issue. However, these two studies are limited in terms of the research tool used (i.e., descriptive statistics and correlation analysis), and the relatively small socio-demographic profile of the surveyed population (the former based on 132 UK respondents, while the latter focused on 326 Polish participants). Further, these two studies did not examine customers’ WTP for LCJF use in commercial aviation—a critical construct for aviation decarbonisation (Ahmad and Xu, 2021).

Along with the acceptance of LCJF, efforts have been made to investigate the level of support for various policy options for curbing aviation carbon emissions. In this context, Kantenbacher et al. (2018) surveyed the British population to find their opinions on 14 various policy levers. The study found that the public supports policies that do not put any financial burden on the individual; rather, the aviation industry should bear the burden of any carbon mitigation developments. They also found that efforts should be made to develop alternatives to air travel. However, public opinion of LCJF was not made part of the enquiry.

A survey of air passengers conducted by Hooper et al. (2008) found that passengers do not see themselves as responsible for the climate impacts of their flights. Instead, their belief was that environmental impact should be dealt with by the respective governments or the airlines themselves. It can be inferred from their study that the general public needs to be further made aware of the environmental impact of aviation in order to reduce the awareness-attitude gap.

To the best of the authors’ knowledge, only two studies, namely Rains et al. (2017), and Rice et al. (2020), explicitly assessed customers’ WTP for LCJF use. Meanwhile, a third study by Goding et al. (2018) focused narrowly on the WTP of business travellers only. More specifically, Rains et al. (2017) found that customers are willing to pay a 13% price premium, while Rice et al.’s (2020) findings indicate that the public is ready to pay an additional ticket fee (under 15% of the price) in proportion to the level of emission reduction. Likewise, Goding et al. (2018) estimated a price premium of 11.9% to the base ticket price. Though the valuation of WTP is useful from the airlines’ perspective, these studies have omitted the wider societal psychology surrounding WTP. Nevertheless, these studies form the theoretical basis of our study. Hence, the present study focuses on determining the general public’s perception of the benefits and risks associated with LCJF use, their social trust in institutions dealing with LCJF, and their attitude manifested in their willingness to pay more for eco-friendly LCJF.

In summary, we infer from the literature review performed that there is a need to further explore the public’s perception of and attitude toward LCJF use in aviation. This is because the lack of public knowledge of aviation-related emissions can hamper any efforts aimed at mitigating them and decarbonising aviation. Moreover, social trust in key players has not been adequately explored. Likewise, it is vital to explore how the public perceives the benefits and risks of LCJF use, especially when they are indirect and related to society rather than direct and related to an individual (van de Velde et al., 2011). There is no doubt that LCJF are expensive to use in the foreseeable future; hence, it is inevitable for airline companies to raise their ticket selling prices. It is important, therefore, to investigate WTP premium prices for greener flying while, more importantly, trying to understand and establish what influences WTP.

3. Research design

The primary data for our study were collected via a quantitative survey to ensure a good representation of public views toward WTP for LCJF from the larger population. Fig. 1 summarises the research design while a detailed description is provided below.

3.1. Survey instrument

Several frameworks and theories, including but not limited to the technology acceptance model (TAM), theory of interpersonal behaviour (TIB), and innovation diffusion theory (IDT), can be applied to investigate LCJF adoption and WTP. In this study, we based our approach on a theoretical underpinning from Ajzen’s (1985) Theory of Planned Behaviour to seek a novel insight supporting WTP for LCJF. Recall that the TPB postulates intention as the primary construct that influences behaviour, and is determined by the subjective norm, perceived behaviour control, and attitude toward the behaviour (Ajzen, 1991). Our motivation for using the TPB is that it provides a broad view of social-psychological constructs to understand citizens’ behaviour in their relative contexts (Kollmuss and Agyeman, 2002; Mattison and Norris, 2007); in our case, WTP for LCJF. This theoretical foundation has also been used in more general exploration of bioenergy in the literature, such as in the study by Halder et al. (2017).

To develop our survey instrument, we used perception as a construct to understand what the public thinks about LCJF use. As perception guides actions (Radics et al., 2015) and to obtain a richer picture, we further divided perception into perceived benefits and perceived risks (Filimonou et al., 2018). The confidence in institutions (e.g., academic, government, and industry) plays a major role in developing public

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6 The reader is referred to Sadoughi et al. (2019) for a comprehensive review of these frameworks and theories.

7 Bioenergy primarily including heat and electricity.
attitude (Amin et al., 2017). Therefore, to reflect trust in institutions, we included the construct of social trust in our instrument. The attitude construct (Filimonau and Högström, 2017; Kantenbacher et al., 2018) aims to explore the public’s views regarding the usefulness of LCJF. Lastly, the WTP (Rains et al., 2017) construct was included to determine the public’s behavioural intention toward LCJF use. The constructs and the corresponding items to measure them are presented in Table 1.

First, we divided the questions around public perceptions of LCJF into benefits and risks components. Perceived benefits are concerned with the extent to which 1) the investments in LCJF will benefit both the economy and society, 2) LCJF use can greatly help in safeguarding the environment, 3) using LCJF will reduce the country’s dependence on foreign oil, 4) LCJF can reduce conventional jet fuel dependence, and 5) the benefits of using LCJF exceed other GHG emissions reduction measures in aviation. Perceived concerns, on the other hand, measure the extent to which 1) LCJF pose a safety concern; 2) higher LCJF production would lead to an increased competition for agricultural land; 3) LCJF production would harm the ecosystem; 3) LCJF take more energy to make than it is worth; and, (5) there is not enough LCJF to meet demand. Second, social trust in whether major stakeholders (e.g., academic, government, and businesses) are doing a good job to promote LCJF was assessed by the following three items: 1) the extent to which the scientific community is doing a good job for society by developing LCJF; 2) the extent to which LCJF producers are helping society; and 3) the extent to which the government or policymakers are doing a good job to promote LCJF. In response to the panel’s feedback, minor adjustments were made to the survey questions.

In addition, we included several standard demographic variables (e.g., age, education, gender) to examine the variance of attitude toward LCJF across different groups. The location variable consisted of four countries representing the UK. Finally, respondents were asked to describe their flying behaviour and carbon off-setting mechanisms. For the former, respondents were asked to record the number of flights typically taken in a year while the latter gave five choices to be ranked from the most to the least appropriate.

3.2. Survey distribution

To obtain data for the survey, a well-established third-party market research organisation, namely Qualtrics, was commissioned. The panel survey was administered online using the Qualtrics® platform during a three-week period in January 2020. The third-party organisation ensured a sample size that represented the UK population aged 16 and

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8 Safety concerns are associated with fuel ignition risk during (de)fuelling and storage, and fuel vapour inhalation by humans, among other technical concerns of fuel characteristics (ICAO, 2016; van Dyk and Saddler, 2021).

9 To be more specific, we divided the educational achievement into primary education or less, secondary education, post-secondary education below degree level, bachelor’s or equivalent, and master’s/higher degree or equivalent. Employment status comprised of five general categories: student, full-time employed, part-time employed, unemployed, and retired.
Table 1
Survey Constructs, Measuring Items, and Their Reliability Statistics.

| Construct            | Cronbach’s Alpha | Items                                                                 | KMO measure of sampling adequacy | Bartlett’s test of sphericity |
|----------------------|------------------|----------------------------------------------------------------------|----------------------------------|------------------------------|
| Perceived benefits   | 0.88             | Investments in LCJF will benefit both the economy and the society.   | 0.873                            | $\chi^{(10)} = 2479.23, p < 0.001$ |
|                      |                  | LCJF use can greatly help in protecting the environment.             |                                  |                              |
|                      |                  | Using LCJFs will reduce the dependence on foreign oil.               |                                  |                              |
|                      |                  | LCJF can reduce conventional jet fuel dependence.                    |                                  |                              |
|                      |                  | The benefits of using LCJF exceed other GHG emissions reduction measures in aviation. |                                  |                              |
| Perceived risks      | 0.75             | LCJF pose a safety concern.                                          | 0.610                            | $\chi^{(3)} = 644.10, p < 0.001$ |
|                      |                  | A higher production of LCJF would lead to an increased competition for agricultural land. |                                  |                              |
|                      |                  | LCJF production would harm the ecosystem.                            |                                  |                              |
|                      |                  | LCJF take more energy to make than it is worth.                      |                                  |                              |
| Social trust         | 0.72             | The scientific community is doing a good job for the society by developing LCJF. | 0.616                            | $\chi^{(3)} = 679.83, p < 0.001$ |
|                      |                  | LCJF producers are helping the society.                              |                                  |                              |
|                      |                  | Government/ Policymakers have done a good job so far in regulating LCJF. |                                  |                              |
| Attitude             | 0.77             | I believe it is a good idea to use LCJF for flights.                 | 0.752                            | $\chi^{(10)} = 1678.63, p < 0.001$ |
|                      |                  | I dislike the idea of using LCJF for flights.                        |                                  |                              |
|                      |                  | I would prefer flying with airlines using LCJF.                      |                                  |                              |
|                      |                  | I would encourage others to fly on flights using LCJF.               |                                  |                              |
|                      |                  | I would like to know more about LCJF.                               |                                  |                              |
| Willingness to pay   | 0.88             | I would be willing to pay a higher ticket price for my flights using LCJF. | 0.713                            | $\chi^{(3)} = 1837.60, p < 0.001$ |
|                      |                  | I would be willing to pay a higher ticket price for flights using LCJF. |                                  |                              |

Table 1 (continued)

| Construct            | Cronbach’s Alpha | Items                                                                 | KMO measure of sampling adequacy | Bartlett’s test of sphericity |
|----------------------|------------------|----------------------------------------------------------------------|----------------------------------|------------------------------|
|                      |                  | ticket price for using LCJF even if a cheaper flight using regular jet fuel is available. |                                  |                              |
|                      |                  | I would be willing to choose a flight that uses LCJF regardless of the flight ticket price. |                                  |                              |

...over, satisfying a minimum of 95% confidence level. Following Bushman et al. (2012), Len-Ríos et al. (2016), Moreno et al. (2021), and more recently, Sewell et al. (2022), a nonprobability sampling approach was adopted. Further, Heen et al. (2014) showed that online recruitment approaches using tools such as Qualtrics can achieve demographic attributes that are typically within a 10% range of their corresponding values.

3.3. Data analysis and reliability

Where appropriate, items designed to measure perceived benefits, perceived risks, social trust, attitude, and WTP were reverse-coded so that a response value of 1 (strongly disagree) now represents a response of 5 (strongly agree). Only one item from the attitude construct was reverse-coded to reflect an affirmative attitude toward the LCJF use. Note that single-respondent surveys, like ours, may face the common method bias, which can adversely affect the reliability and validity of measures and parameter estimations (Jordan and Troth, 2020). To address this concern, we applied Harman’s single factor test to determine if most of the variance can be explained by a single factor. Following Podsakoff et al. (2003), we performed exploratory factor analysis and found that no single factor explains a substantial portion of the total variance among measures. The total variance extracted by a single factor was 28.31%. Therefore, we argue that the common method bias is not present in our study.

The internal consistency of all five constructs was measured by Cronbach’s alpha. Note that a Cronbach’s alpha of ‘0’ denotes no internal reliability, while a value of ‘1’ denotes perfect internal reliability. A threshold of 0.7 was used as the benchmark for construct reliability (Emma et al., 2019). Table 1 shows that all five constructs in this study had strong internal consistency, with alpha values above the mentioned threshold. In addition to construct reliability, we also investigated how each item factored into a construct using principal component analysis. In our study, the perceived benefits, perceived risks, and attitude constructs comprised five items each, while social trust and WTP had three items each. To confirm the factor analysis, we used the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett’s test of sphericity. Keeping in line with the aim of our work, we used ordered logistic regression to predict the factors that influence WTP for LCJF.

4. Results and discussion

4.1. Respondent characteristics

Our survey invitation was extended to 2000 respondents. We received 1081 responses, of which 73 were dropped due to incomplete...
or missing data. This left us with a final sample of 1008 responses and a final response rate of ~50% to conduct our analyses. Similar studies had a response rate ranging from ~9% (Chavez et al., 2021) to ~40% (Smith et al., 2018).

This final sample comprised 54% female respondents and 46% male respondents (Table 2). The participants’ ages varied from 18 to 92, with an average age of 46 years. Most of the respondents are from England (87%), followed by Scotland (7.5%), Wales (4.2%), and Northern Ireland (1.3%). This distribution is consistent with the populations in England, Scotland, Wales, and Northern Ireland. Only ~17% of participants were classified as ‘frequent flyers’ as they had flown more than three times over the previous year. Overall, the number of participants who did not fly over the past year was large at 37%, while the percentage of those who flew once or twice added up to ~63%. Hence, given the high proportion of non-frequent flyers and the fact that perception of and attitude toward LCJF could be expressed even if a respondent does not typically fly, a decision was made to include them in the analysis. Finally, a good majority of participants were educated to university level (~40%).

4.2. Perceived benefits

In terms of perceived benefits, most of the participants perceived LCJF as environmentally, economically, and socially beneficial (Table 3). These benefits in producing and using low carbon fuels conform to those in other studies, particularly in aviation (Gegg et al., 2014; Smith et al., 2017), and the road transport sector, in general (Longstaff et al., 2015). These benefits include emissions reduction potential, fuel diversification, and supply security in addition to enhanced regional/rural development.

Our survey showed that around 58% (or 3 in every 5) of the participants agreed that investments in LCJF production facilities would bring prosperity to the local economy, and to society, in general. A slightly higher proportion of participants (~59%) expressed that using LCJF could be instrumental in protecting the environment. A nationalistic pattern was observed when a high proportion of the participants (56%) took LCJF as a means to reduce foreign oil dependence, compared to only 1.2% who expressed the opposite. Likewise, participants showed their confidence in LCJF as a means to reduce conventional jet fuel dependence, with 57.8% of the participants being optimistic about the notion, while 5.2% were characterised by scepticism. An interesting behaviour was observed when more than half of the participants recorded ‘neither agree nor disagree’ for the statement according to which the benefits of using LCJF exceed other GHG emissions reduction measures in aviation. Though the participants did recognise the LCJF contribution in emission mitigation efforts, there seemed to be a significant gap in their understanding and awareness of the LCJF characteristics that would achieve emissions reduction. This further strengthens the notion that LCJF use in aviation needs promotion.

4.3. Perceived risks

Several risks relating to the availability, production, and safety of LCJF were investigated in this study. While the participants understood the benefits of LCJF use (section 4.2), at the same time, they were apprehensive about the associated risks (Table 4). The biggest of such concerns was the lack of LCJF availability, with ~55% of participants believing that the supply of LCJF is insufficient to meet airlines’ demands. The availability of LCJF has previously been highlighted as a major risk in LCJF’s ability to replace conventional fossil-jet fuel, in terms of amount of fuel available (Gegg and Wells, 2017; Reed, 2016), and refineries and transportation infrastructure (Smith et al., 2017). The second biggest perceived risk relates to the food versus fuel dilemma, with 47% of the participants believing that LCJF production would compete for cropland. However, it is to be noted that an almost similar proportion of respondents (41.8%) were ‘neutral’ on the subject. This result indicated that the food versus fuel controversy was not as fierce as it had previously been reported by Herrmann et al. (2018), Montefrio and Sonnenfeld (2011), and Tenenbaum (2008). Within the sample, 54.1% and 43.7% were undecided on whether LCJF take more energy to make than it is worth and on whether LCJF pose a safety concern, respectively. This situation suggested the participants’ lack of information on LCJF production process (i.e., how non-fossil feedstock is converted into jet fuel) and technical characteristics. Therefore, it points to the need to disseminate LCJF-related information more widely to the public.

Contrary to our study, Filimonau et al. (2018) investigated the LCJF safety issue from a non-technical perspective, which seems unnecessary as all LCJF must be internationally certified before they can be used. Lastly, a large proportion of the participants (46.4%) declared not being sure whether LCJF production would harm the ecosystem. This finding was contradictory to the reality where LCJF production is deemed environmentally benign (ATAG, 2011). Overall, the risk perception analysis revealed an interesting conundrum in this survey: though the use of LCJF is believed to protect the environment (limiting carbon emissions), its production is considered to harm the environment (in terms of soil and water pollution). However, this complex situation can be dealt with by providing comprehensive information on LCJF such that the pros and cons of this innovation are adequately understood by the public.

4.4. Social trust

The social trust construct investigated confidence in relevant institutions (i.e., policymakers, scientific community, and LCJF producers). These key players have the legitimacy and power to shape how the public views LCJF. Our survey showed a varying level of trust in all the key players. The participants demonstrated a high level of trust in LCJF producers, followed by the scientific community. The least level of trust was shown in policymakers’ efforts related to LCJF development. Around 20% of participants only recognised policymakers’ efforts. Table 5 summarises our findings. Particular to aviation, Filimonau et al. (2018) observed the same low level of trust in government and its affiliates dealing with LCJF as in our study. A similar pattern of trust is presented in a study by Longstaff et al. (2015), where the majority of the respondents felt left out in government deliberation on low carbon fuels. Furthermore, our survey results revealed an alarming situation. For all
three key players in LCJF, nearly half of the participants recorded ‘neither agree nor disagree’ relating to the trust level. This finding points to the importance of public engagement by these key players in policymaking, production, and the technological development process in a wider LCJF acceptability context.

4.5. Attitude

To gauge participants’ attitude toward LCJF, five items were used in our survey, the results of which are presented in Table 6. Our survey results showed an overall positive attitude toward LCJF use. For all the items, approximately one third, and in some cases more than half of the participants, remained in the ‘agree’ and ‘strongly agree’ categories. A significant proportion of participants not only showed a keen interest in learning more about LCJF (~64%), they also believed it to be a good idea to use it for flights (~53%). When considering taking flights using LCJF, ambivalence was noted in participants’ responses. The difference between the undecided (45.9%) and the combined ‘agree’ categories

Table 3
Public Perceived Benefits of LCJF use in aviation (%).

| Perceived Benefits | Strongly Disagree (1) | Disagree (2) | Neither Agree Nor Disagree (3) | Agree (4) | Strongly Agree (5) | Mean (SD)  |
|--------------------|-----------------------|--------------|-------------------------------|-----------|--------------------|------------|
| 1) Investments in LCJF will benefit both the economy and the society. | 1.8 | 3.2 | 37.0 | 41.4 | 16.7 | 3.68 (0.850) |
| 2) LCJF use can greatly help in protecting the environment. | 2.4 | 3.5 | 35.0 | 41.2 | 18.0 | 3.69 (0.887) |
| 3) Using LCJFs will reduce the dependence on foreign oil. | 1.2 | 5.2 | 37.8 | 43.2 | 12.7 | 3.61 (0.817) |
| 4) LCJF can reduce conventional jet fuel dependence. | 1.8 | 3.4 | 37.0 | 45.4 | 12.4 | 3.63 (0.810) |
| 5) The benefits of using LCJF exceed other GHG emissions reduction measures in aviation. | 2.4 | 4.0 | 54.9 | 30.5 | 8.3 | 3.38 (0.791) |

Note. SD = Standard Deviation.

Table 4
Public Perceived Risks of LCJF use in aviation (%).

| Perceived Risks | Strongly Disagree (1) | Disagree (2) | Neither Agree Nor Disagree (3) | Agree (4) | Strongly Agree (5) | Mean (SD) |
|-----------------|-----------------------|--------------|-------------------------------|-----------|--------------------|-----------|
| 1) LCJF pose a safety concern. | 4.5 | 22.3 | 43.7 | 24.2 | 5.4 | 3.04 (0.926) |
| 2) A higher production of LCJF would lead to an increased competition for agricultural land. | 0.6 | 10.9 | 41.8 | 37.6 | 9.1 | 3.44 (0.827) |
| 3) LCJF production would harm the ecosystem. | 4.6 | 22.9 | 46.4 | 19.8 | 6.3 | 3.00 (0.928) |
| 4) LCJF take more energy to make than it is worth. | 3.0 | 16.0 | 54.1 | 21.1 | 5.9 | 3.11 (0.844) |
| 5) There is not enough LCJF to meet the demand. | 1.4 | 5.4 | 38.7 | 40.1 | 14.4 | 3.61 (0.847) |

Note: SD = Standard Deviation.

Table 5
Social Trust in Institutions regarding LCJF development (%).

| Social trust | Strongly Disagree (1) | Disagree (2) | Neither Agree Nor Disagree (3) | Agree (4) | Strongly Agree (5) | Mean (SD) |
|--------------|-----------------------|--------------|-------------------------------|-----------|--------------------|-----------|
| 1) The scientific community is doing a good job for the society by developing LCJF. | 2.3 | 6.5 | 59.4 | 26.2 | 5.6 | 3.26 (0.757) |
| 2) LCJF producers are helping the society. | 1.8 | 3.8 | 42.1 | 42.5 | 9.9 | 3.55 (0.793) |
| 3) Government/Policymakers have done a good job so far in regulating LCJF. | 6.3 | 15.5 | 58.2 | 14.8 | 5.3 | 2.97 (0.873) |

Note: SD = Standard Deviation.
(47%) seemed trivial. However, slightly higher agreement over being undecided (43.3%) was recorded for encouraging others to take flights using LCJF (46.3%). Like before, this behaviour can be attributed to a lack of knowledge about the use of LCJF.

4.6. Willingness to pay for LCJF use

In our study, we defined a scale for WTP (or for paying more) based on three items. The three items were designed to check the voluntary and involuntary WTP for LCJF, while the third item disregarded the ticket price – see Table 7. For the involuntary WTP a higher ticket price for flights using LCJF, we found 28.4% of the participants in agreement with the statement, while the majority (37.7%) categorically rejected the notion. For voluntary WTP a higher ticket price, despite the availability of cheaper flights, we found that the participants were not willing to pay a higher price. Only 25.6% agreed, while the majority of the respondents (38.9%) expressed an interest in cheaper flights using regular jet fuel. Similarly, a low percentage of participants agreed to take flights with LCJF regardless of the flight ticket price (23.5%); by contrast, 34.6% disagreed. We can conclude, therefore, that the flight ticket price plays a major role. On the WTP scale, we found an average of 37% of the participants were undecided on all three items.

Our findings contradict previous research done on air travellers’ WTP for carbon neutral aviation, such as the studies by Choi et al. (2018) and Seetaram et al. (2018). However, the main difference that can be attributed to our case is that the literature does not specifically include LCJF as an option for carbon neutrality, instead focusing on presenting carbon taxes or air passenger duty, renewable energy projects, afforestation projects, and environmental education as options (Røsehans et al., 2020).

4.7. Predictors of willingness to pay for LCJF

Along with the exploratory endeavour, one of the aims of this study was to determine which factors determine WTP for LCJF. First, we examined the zero-order correlations among the primary measures of social trust, perceived benefits, perceived risks, attitude, and willingness. As presented in Table 8, we found that WTP was positively and significantly correlated with social trust (0.370, p < 0.01), perceived benefits (0.327, p < 0.01), perceived risks (0.173, p < 0.01), and attitude (0.365, p < 0.01). However, the correlation between WTP and perceived risks was found to be small, albeit significant. Attitude was positively and more substantially correlated with perceived benefits (0.356, p < 0.01). As one would expect, attitude and perceived risks presented averse relation implied that the participants with reservations toward LCJF were less inclined toward the idea of LCJF use.

Furthermore, we included the measures of perceived benefits, perceived risks, social trust, and attitude, as well as demographics, to predict WTP for LCJF. We carried out the prediction analysis using ordered logistic regression. We used three dependent variables, namely WTP1, WTP2, and WTP3, corresponding to the items composing WTP in Table 8. It is to be noted that the independent variables have been regressed with item-level WTP for better explainability. To explore the demographic effect on WTP, the variables of age, gender, education, location, occupation, donation, and flying frequency were added. This setting provided practicality to analysing the three WTP variables in a single hierarchical model rather than testing them separately. In addition, we performed various tests to ensure our data satisfy the underlying assumptions for ordinal logistic regression (e.g., linearity, no outliers; independence; no multicollinearity).

The ordered logistic regression revealed that social trust, perceived risks, and attitude were found to be significant predictors of WTP1 ("willing to pay a higher ticket price for my flights using LCJF") for both Models 1 and 2 – see Table 9. On the other hand, perceived benefits was not found to be a statistically significant predictor. With the addition of the demographic variables, the McFadden’s pseudo-R-squared value increased from 0.089 (model 1) to 0.097 (model 2). However, only the variables of age and education level were found to be significant predictors.

Looking at the ordered log-odds coefficients (Table 9), the results indicated that by increasing the social trust score by one point, the ordered logits of a respondent in a higher category of WTP1 would increase by 24%, while the other variables in the model are held constant. It can be inferred that by increasing social trust, WTP1 increases. Participants who are more concerned about LCJF are 13% less likely to be in higher categories of agree or strongly agree to pay for LCJF along with participants with a higher education level. Similarly, with a unit increase in attitude and education, the ordered log-odds of a respondent in a higher category of WTP1 would increase by 21.5% and 1.1%, respectively, while other variables in the model are held constant. Finally, the ordered log-odds showed that the older population was 1.1% less likely than the younger population to be in a higher category of WTP1. This suggests that older air travellers were less likely to pay a higher flight ticket price for LCJF use.

The second dependent variable in our study, WTP2, explored WTP for a higher ticket price using LCJF even if a cheaper flight using regular jet fuel was available. The ordered logistic regression revealed that social trust, perceived risks, and attitude were significant predictors of WTP2 – see columns 4 and 5 in Table 9. The third and final dependent variable evaluated in our study, WTP3, investigated the willingness to choose a flight that uses LCJF regardless of the flight ticket price – see columns 6 and 7 in Table 9. The ordered logistic regression found that social trust, perceived risks, attitude, and age played an important role in explaining WTP3.

In general, the results suggested that participants with a positive

| Willingness to pay | Strongly Disagree (1) | Disagree (2) | Neither Agree Nor Disagree (3) | Agree (4) | Strongly Agree (5) | Mean (SD) |
|--------------------|------------------------|-------------|-------------------------------|----------|-------------------|----------|
| 1) I would be willing to pay a higher ticket price for my flights using LCJF. | 16.4 | 21.3 | 33.8 | 21.8 | 6.6 | 2.81 (1.15) |
| 2) I would be willing to pay a higher ticket price for using LCJF even if a cheaper flight using regular jet fuel is available. | 16.1 | 22.8 | 35.5 | 19.9 | 5.7 | 2.76 (1.11) |
| 3) I would be willing to choose a flight that uses LCJF regardless of the flight ticket price. | 15.8 | 18.8 | 41.9 | 16.4 | 7.1 | 2.80 (1.11) |

Note: SD = Standard Deviation.
attitude toward LCJF, trust in the effort of key players, and those who perceived more benefits, were in agreement to pay more for LCJF, with the exception of those who showed concerns about LCJF use. To further ensure the robustness of our findings, we examined whether excluding those aged over 79 would make a difference. The results from these exercises did not qualitatively change our main findings.\textsuperscript{11}

5. Conclusions

Despite the potential for LCJF to decarbonise the aviation industry, the uptake of LCJF remains in its infancy stage. There is a lack of in-depth investigation of public opinion on the use of LCJF in aviation, particularly WTP for higher ticket prices. To fill the above gaps, we constructed a comprehensive survey and gathered a large sample of UK public views on LCJF. We achieved the primary objective of our work by determining the significant factors that would predict WTP for LCJF. Findings from this study pointed out that WTP can be explained by five key factors.

Three of these five variables comprised social trust, attitude, and perceived risks. The predictor of social trust is particularly interesting because citizens seem to currently be aware of the efforts being made by the government, industry, and research institutions. However, it is logical that the more the institutions promote and endorse their commitment to LCJF, the greater the public’s trust and their willingness to pay would be. As seen with social trust, with a higher rating of attitude, the public’s WTP increases. Our findings are in line with prior research that established that having a positive attitude exhibits itself in the intended behaviour (Van Dael et al., 2017). Unlike with social trust and attitude, as the participants’ rating of perceived risks increases, their WTP decreases. The negative relationship between the perceived risks and WTP makes sense, as individuals who have apprehensions about LCJF would rate the risk high and be less willing to pay for tickets for flights using LCJF. Finally, the predictors of education level and age were found to be significantly related to WTP. With a higher level of education, it is possible that either social trust increases or the perceived risks decrease. In either case, education level leads to increased WTP. While age was found to also be a significant predictor, it is acknowledged that its contribution either case, was not found to be significant.

Our study provides valuable insights to decision-makers, both in the government and industry, for framing strategies in the short run and policies in the long run, which would strengthen the public’s perception and attitude, in turn resulting in their increased WTP for LCJF use in aviation. For LCJF to produce the benefits that policymakers and airlines seek, the public must actively engage with LCJF production technology. While doing so, emphasis should be placed on the emissions reduction potential offered by LCJF, and its implications for fuel sustainability. However, we also recognise that any attempt to promote WTP for LCJF will inevitably face structural barriers not likely to be resolved by outreach and marketing campaigns. For instance, as our findings indicate, older respondents are not willing to pay a premium ticket price. To develop trust, key players must devise mechanisms to promote their domain interventions in the form of relevant marketing campaigns, particularly WTP. This can be achieved by promoting LCJF, their production and attitude, in turn resulting in their increased WTP for LCJF use in aviation. For LCJF to produce the benefits that policymakers and airlines seek, the public must actively engage with LCJF production technology. While doing so, emphasis should be placed on the emissions reduction potential offered by LCJF, and its implications for fuel sustainability. However, we also recognise that any attempt to promote WTP for LCJF will inevitably face structural barriers not likely to be resolved by outreach and marketing campaigns. For instance, as our findings indicate, older respondents are not willing to pay a premium ticket price. To develop trust, key players must devise mechanisms to promote their domain’s contributions among the public. Likewise, our study found that the public do perceive benefits of LCJF and its impact on fuel sustainability. However, we also recognise that any attempt to promote WTP for LCJF would not resolve the barrier to be placed on the emissions reduction potential offered by LCJF, and its implications for fuel sustainability. However, we also recognise that any attempt to promote WTP for LCJF would not likely be resolved by outreach and marketing campaigns. For instance, as our findings indicate, older respondents are not willing to pay a premium ticket price. To develop trust, key players must devise mechanisms to promote their domain’s contributions among the public. Likewise, our study found that the public do perceive benefits of LCJF within the environmental, social, and economic domains, but also associate risk with LCJF availability and the environmental impact of its production. This highlights a potential need for airlines to devise future interventions in the form of relevant marketing campaigns, particularly to gain support from the younger population. Likewise, to ensure the

\textsuperscript{11}We thank an anonymous reviewer for suggesting that the state of health can also play a key role in influencing older respondents’ willingness to pay. The results are available upon request.

Table 9

Ordered Logistic Regression for WTP for LCJF.

|                | WTP1 | WTP2 | WTP3 |
|----------------|------|------|------|
|                | Model 1 | Model 2 | Model 1 | Model 2 | Model 1 | Model 2 |
| Social Trust   | 0.283* | 0.245* | 0.265* | 0.215* | 0.293* | 0.242* |
|                | (5.68) | (4.70) | (5.46) | (4.27) | (6.30) | (4.99) |
| Perceived Benefits | 0.00103 | 0.00984 | -0.0349 | -0.0205 | -0.00773 | 0.0157 |
|                | (0.03) | (0.32) | (-1.15) | (-0.67) | (-0.24) | (0.49) |
| Perceived Risks | -0.141* | -0.130* | -0.144* | -0.131* | -0.147* | -0.135* |
|                | (5.18) | (4.69) | (5.25) | (4.66) | (5.31) | (4.84) |
| Attitude       | 0.223* | 0.215* | 0.199* | 0.195* | 0.185* | 0.184* |
|                | (7.83) | (7.41) | (6.86) | (6.54) | (6.21) | (6.14) |
| Female         | 0.184 | (1.49) | 0.160 | (1.28) | 0.0254 | (0.21) |
| Age            | -0.0117* | -0.0166* | -0.0166* | -0.0166* | -0.0166* | -0.0166* |
|                | (-2.40) | (-3.23) | (-3.23) | (-3.23) | (-3.23) | (-3.23) |
| Location       | -0.000456 | -0.0213 | -0.0213 | -0.0213 | -0.0213 | -0.0213 |
|                | (-0.01) | (-0.31) | (-0.31) | (-0.31) | (-0.31) | (-0.31) |
| Occupation     | 0.0566 | 0.0294 | -0.0495 | -0.0495 | -0.0495 | -0.0495 |
|                | (1.42) | (0.73) | (-1.21) | (-1.21) | (-1.21) | (-1.21) |
| Donation       | 0.0000576 | 0.0000375 | 0.0000375 | 0.0000375 | 0.0000375 | 0.0000375 |
|                | (1.21) | (1.94) | (1.94) | (1.94) | (1.94) | (1.94) |
| Education      | 0.140* | 0.0832 | 0.0131 | 0.0131 | 0.0131 | 0.0131 |
|                | (2.14) | (1.29) | (0.21) | (0.21) | (0.21) | (0.21) |
| Flying Frequency | 0.0826 | 0.132 | 0.0148 | 0.0148 | 0.0148 | 0.0148 |
|                | (0.97) | (1.59) | (0.18) | (0.18) | (0.18) | (0.18) |
| N              | 1008 | 1008 | 1008 | 1008 | 1008 | 1008 |
| Npseudor2      | 0.0894 | 0.0977 | 0.0705 | 0.0819 | 0.0779 | 0.0931 |

Note: Standard errors in parentheses.
\* \textit{p} < 0.10.
\textsuperscript{11} \textit{p} < 0.05.
\textsuperscript{11} \textit{p} < 0.01.
availability of LCJF, policymakers can investigate various mechanisms that would increase LCJF production, ensuring that a sufficient volume of fuel is available, for example, by incentivising production or setting up mandates.

In terms of future studies, we aim to assess whether a neutral disposition toward the risk perception and social trust constructs is due to a lack of awareness leading to indecisiveness or whether it is due to the ubiquitous attitudes of participants. Second, we plan to evaluate the links between the psychometric constructs considered in this study in order to draw any correlational inference between them. Furthermore, by recognising the influence of the media in framing public attitudes (Delsahad and Raymond, 2013), our future research would look into how media portrays LCJF use in aviation. Another line of inquiry that could be explored is to widen the scope of key players in our study and assess the general public’s opinion about the role played by international consortiums, such as the Sustainable Aviation Alternative Fuels Users Group and ICAO, in the LCJF development (Gegg et al., 2014).

CRediT authorship contribution statement

Bing Xu: Conceptualization, Supervision, Project administration, Formal analysis, Writing – original draft, Writing – review & editing. Salman Ahmad: Methodology, Software, Investigation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing. Vincent Charles: Validation, Visualization, Writing – review & editing. Jin Xuan: Conceptualization, Validation, Supervision, Writing – review & editing.

Declaration of competing interest

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

Data availability

The data that has been used is confidential.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.133990.

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