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Public Acceptance of a Proposed Sub-Regional, Hydrogen–Electric, Aviation Service: Empirical Evidence from HEART in the United Kingdom

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Abstract: This paper addresses public acceptance of a proposed sub-regional, hydrogen–electric, aviation service reporting initial empirical evidence from the UK HEART project. The objective was to assess public acceptance of a wide range of service features, including hydrogen power, electric motors, and pilot assistance automation, in the context of an ongoing realisable commercial plan. Both qualitative and quantitative data collection instruments were leveraged, including focus groups and stakeholder interviews, as well as the questionnaire-based Scottish National survey, coupled with the advanced discrete-choice modelling of the data. The results from each method are presented, compared, and contrasted, focusing on the strength, reliability, and validity of the data to generate insights into public acceptance. The findings suggest that public concerns were tempered by an incomplete understanding of the technology but were interpretable in terms of key service elements. Respondents' concerns and opinions centred around hydrogen as a fuel, single-pilot automation, safety and security, disability and inclusion, environmental impact, and the perceived usefulness of novel service features such as terminal design, automation, and sustainability. The latter findings were interpreted under a joint framework of technology acceptance theory and the diffusion of innovation. From this, we drew key insights, which were presented alongside a discussion of the results.

Keywords: technology acceptance; diffusion of innovation; hydrogen aviation; electric aircraft; sub-regional aviation; public acceptance; inclusive design

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1. Introduction

This paper reports work on the HEART project, which is underpinned by a novel hydrogen electric technology using hydrogen fuel cells and electric aviation engines. Based on sub-regional services in Scotland, sustainable small terminal design, and automation innovations in both, this research concerns the public acceptance of the proposed HEART service, which includes a number of innovative features. The research reported initially addresses the public acceptance of service features.

The aviation sector has been under long-term pressure to reduce its contribution to climate change, as it is one of the fastest-growing sources of greenhouse gas emissions, emitting almost 900 million tons of carbon dioxide CO_2 per year [1]. This is due to increased air travel demand. Air transport contributes 12% of the global CO_2 transport emissions [2], and the demand for it is expected to double by 2050 [3]. Emerging in response to the decarbonisation of the aviation sector, hydrogen electric technologies are central to supporting greener air travel in the future [4,5].

The Champion Report [6] considers the UK aviation sector to be an exceptional platform for the innovation and commercialisation of technologies related to hydrogen. The goal of net zero has been set in the UK domestic aviation industry for 2050, which demands the fast development of new technologies. The target is to double the production of green hydrogen in the UK from 5 GW to 10 GW by 2030. The adoption and release of hydrogen-powered aircraft is an opportunity for the UK to create 38,000 jobs [7]. Hydrogen electric technologies, whereby an electric motor is powered by fuel cells, hold tremendous potential for the aviation sector, as they can help combat climate change without compromising the supply or quality of service provided by the aviation industry [5]. Specifically, the hydrogen-powered aircrafts are expected to generate zero CO_2 emissions during their operation, thus contributing to significant reductions in carbon emissions. Due to their hydrogen-powered motors, their fuel efficiency is higher, leading to lower operating costs for airline companies. The technical challenges that hydrogen aircraft bring include fuel cost, onboard storage, a reduction in aircraft utilisation volume, and integration with other plane structures or mechanisms that involve risk and safety issues due to the use of inert gases in pipes [8,9]. However, the debate still continues over which option, among burning hydrogen or powering fuel cells, offers the best opportunities [10]. Batteries and gaseous hydrogen offer similar energy densities, and the latter can be used to power electric motors via fuel cells, as in HEART. It is likely that gaseous hydrogen would be best applied to power small regional aircraft, while short-, medium-, and long-distance aircraft will need liquid hydrogen. The potential application of gaseous hydrogen for small aircraft has also been discussed [10]. Due to the lower fuel weight, hydrogen aircrafts may have extended ranges; however, new aircraft designs and larger fuel tanks may be needed for long-haul flights. In addition, their lower noise emissions can efficiently reduce the disturbance to the built and physical environment, especially in areas close to airports.

Despite the major benefits that hydrogen aviation is anticipated to bring, there are still several challenges to be investigated further and addressed [11]. There are associated with the required infrastructure at airports (mainly relating to hydrogen storage and distribution); the safety process of handling and using hydrogen in the airport and aircraft; the production process of hydrogen and its environmental performance; the hydrogen supply chain; the regulatory and policy framework needed for the sustainable and financially viable operation of the service; and ultimately, the public acceptance of this emerging technology. Moreover, the use of hydrogen in short-haul flights may yield relatively limited reductions in CO_2 emissions, particularly when compared to the greater potential benefits achievable in long-haul aviation.

Building on these challenges and opportunities, the HEART project emerges as a groundbreaking initiative aimed at advancing hydrogen electric technologies for aviation. It focuses on developing and testing innovative solutions for sub-regional air services in Scotland, including sustainable terminal designs and automation advancements. The project prioritises understanding public acceptance of its proposed service, which incorporates numerous novel features. This study reports the initial findings on public acceptance, marking the first research study on this topic.

Academic and grey literature, such as consultancy and government reports, agree that public attitudes could serve as potential constraints during the adoption of new technology [12–14]. Studies have found that the British population lack awareness about hydrogen technologies, which poses a challenge in terms of hydrogen acceptance and attitudes [15]. Markets need new technologies in order to grow, and some awareness of technologies is essential to connect the gap between niche and large markets [16,17] and reduce public uncertainty [18]. The exposure of new technologies (in this case, hydrogen-related applications) would facilitate public acceptance and foster positive perceptions [18–20]. Flynn et al. [15] found that once the benefits of hydrogen technologies are explained, participants gradually show positive opinions. Furthermore, benefits such as national energy independence and the employment boost from a new hydrogen economy could be a motivator to increase public acceptance of hydrogen technologies.

2. Literature Review

This section discusses evidence, found during the documentary analysis, related to approaches used to examine and explain public acceptance of new technologies related to the HEART service, focusing on hydrogen applications and automation for single-pilot operation.

2.1. Barriers and Challenges of Hydrogen Public Acceptance in Aviation

Major aircraft manufacturers such as Airbus, and players in other aviation industry segments as Bombardier and Zeroavia, have set concrete and tangible near dates to launch commercial hydrogen aviation [21,22], while other manufacturers are more cautious to assess the plausibility of hydrogen aviation [23]. The European Union (EU), through its private–public alliance “Clean Hydrogen Joint Undertaking”, estimates that by 2035 all main European cities can be interconnected by hydrogen-powered aircraft [24]. It is likely that gaseous hydrogen (GAH) would be best applied to power small regional aircraft, while short-, medium-, and long-distance aircraft will need liquid hydrogen (LH). Only [10] explicitly mentions the potential application of GAH for small aircraft, although it is stated without further analysis. Correspondingly, it is difficult to find recent documents that evaluate the application of GAH in regional aviation. It seems that attention has turned to LH. However, this concerns its use in combination with fuel cell (FC) technology, rather than its use to combust hydrogen, for regional aviation.

Another key point is the lack of a comprehensive regulatory framework, which can decisively impact several nuances of technology acceptance [25,26]. An example would be certification related to the safety radius of refuelling powered-hydrogen aircraft [10]. Moreover, researchers that study hydrogen safety with a wider scope claim that policymakers have not paid the same attention to safety implications related to fundamental hydrogen properties [27]. International stakeholders in aviation also lack interest in the hydrogen safety case. Nevertheless, if hydrogen adoption in any form would prevail in the aviation industry, direct costs of aircraft operation are not the only current barriers to be overcome. The production, distribution, and supply chain costs of hydrogen are also part of the essential puzzle that needs further examination alongside the required infrastructure in each of these points. There is not yet solid evidence showing the most cost-efficient option to liquefy hydrogen, i.e., on-site or off-site at the terminal [10].

2.2. Perception and Awareness of Hydrogen as a Fuel

Concerns about the sustainability of hydrogen, infrastructure investment, the maintenance costs of applications, efficiency against fossil fuels, and potential changes in lifestyles emerged as main factors in studies that examined public acceptance [15–17,28]. On the other hand, safety was not among the top concerns of participants, but it was considered a significant aspect [15].

Prior knowledge, cost perception, risk, environmental knowledge, higher education and income, and proximity to hydrogen facilities are the most dominant hydrogen technologies acceptance factors, while infrastructure availability, affordability, local community engagement, regional skill capability development, the preservation of biodiversity, and personal and distributive benefits to the community are crucial for a sustainable hydrogen sector [29]. Historically, evidence demonstrates that the diffusion of energy supply technologies occurs at a slower pace than end-use-related technologies [30].

Recent reviews studies have concluded that the public awareness of hydrogen technologies is low [31,32]. This has not changed substantially compared to similar methodological examinations from the beginning of this century [33]. Some studies suggest that the general public and end-users have no general knowledge of hydrogen in developed countries such as Australia, Germany, Finland, Japan and the UK [30,34,35]. The literature shows that hydrogen infrastructure, such as hydrogen recharging stations with fast refuelling rates, increase social acceptance [36,37]. Furthermore, the likelihood of hydrogen acceptance rises among people living in the vicinity of hydrogen infrastructure as they are familiarised with and eventually have access to hydrogen applications such as hydrogen fuel cell vehicles [31,38].

2.3. Research Methods Applied to Studies of Public Acceptance of Hydrogen Related Technologies

Studies about hydrogen and its implications in the energy transition are predominantly undertaken from a technology perspective. Some examples are [39–41]; few of them include the aviation sector [42,43]. Examinations and assessments related to hydrogen's implications on the macroeconomy seem to be scarce in the academic literature [44]. While the technological dimension has been deeply studied, social impacts and aspects of potential hydrogen commercialisation have not [16].

Gordon et al. [45] developed a study on the future of hydrogen technologies from the public perception and acceptance perspectives. They used seven different empirical studies about levels of hydrogen knowledge and awareness across different developed countries between 2017 and 2023 to support their investigation. None of these sources focused on or discussed, even tangentially, the application of hydrogen in aviation. Furthermore, they examined the literature on public perceptions of hydrogen production systems between 2009 and 2023. Among the eight papers analysed, the public perceptions and opinions about the use of hydrogen production systems in the aviation sector are absent.

Furthermore, it can be observed, in Figure 1, that quantitative strategies, using surveys, prevail as the main employed methodology, with nine papers used to examine public acceptance of hydrogen and related technologies. This confirms that studies about the public perception of hydrogen aviation are scarce, regardless of the chosen methodological approach. Furthermore, the public acceptance of ant hydrogen-related technology remains limited.

Research Gap About Public Acceptance of Hydrogen Related Technologies

It is found that the use of hydrogen as fuel in the transport sector has a very positive perception in the German market [46]; however, assessing acquiescence in aviation is not straightforward [47]. Furthermore, it can be identified that most studies related to the acceptance and perception of hydrogen are associated with road transport, leaving a research gap related to performing similar examinations in the air transport sector [47]. Gordon et al. [45] confirm that the gap remains nearly a decade later.

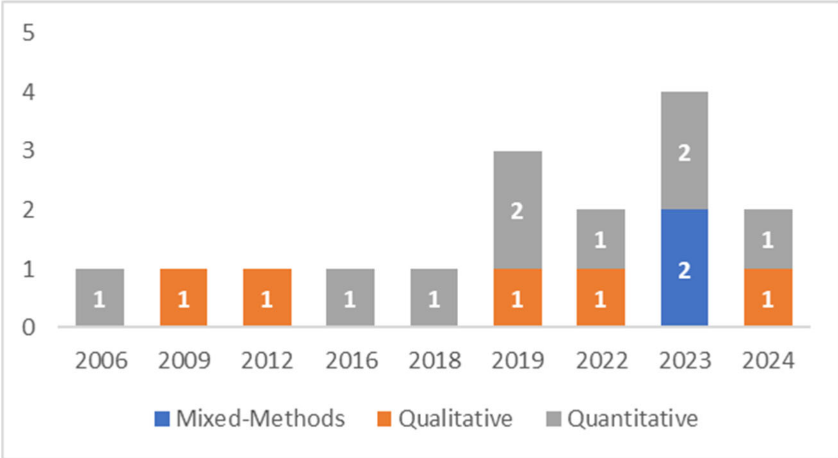

Figure 1. Research methods used to examine public perception and acceptance of hydrogen (adapted from Gordon et al. (2024) [45]).

2.4. Public Acceptance of Single-Pilot and Fully Automated Aircraft

2.4.1. Justification of SPA

Regulations regarding sub-regional commercial aviation do not require two pilots; the use of single-pilot aircraft (SPA) in light applications, such as air taxi and light cargo, is common in the air transport industry. The rigorous scrutiny of pilotless aircraft acceptance is relatively scarce and has received interest recently as there are upward trends in air passenger transport demand and a shortage of pilots in the long term [48,49]. The literature suggests that operating crew costs and a future shortage of pilots are the main justifications for automated aviation [48,49]. If operational costs can be reduced, new routes network might be opened on a regional and sub-regional basis. Consequently, it is foreseen that potential operational cost savings due to SPA could impact short regional flights more significantly than long-haul missions since personnel expenses are more significant in regional and sub-regional aviation [50]. This is extremely relevant to project HEART and is compelling justification for this paper. It is also forecasted that the shortage of pilots will be more dramatic in regional and sub-regional operations as most pilots will migrate to incumbent airline carriers [51]. In this context, SPA is a valid mitigation strategy if the public accept it [52,53].

However, the investment costs of the required technological upgrade for SPA could outweigh the savings of operational costs [54]. Additional, pilots' unions oppose single-pilot operations [55], leading to the rejection of the FAA reauthorization bill in 2017, which aimed to establish a state-funded specific research programme on SPA for cargo operations [56].

2.4.2. Factors That Influence SPA

Quantitative modelling that compares pilotless, remotely piloted, and single-piloted aircraft suggests that the trust of onboard pilot and aviation regulators increases the likelihood of acceptance [57]. Furthermore, an increase in trust in remotely piloted technology does not significantly impact the acceptance of pilotless aircraft technology, but a similar reduction in trust considerably impacts acceptance [58]. On the other hand, trust in the aircraft manufacturers and airlines are not critical factors when willingness to fly is studied.

Overall, 54% of participants in a survey, performed by the inversion bank UBS, stated a low probability to board a pilotless aircraft. Only 17% would intend to board it, and about 50% would not take a flight, even if the ticket fee were significantly lower. Residents in the USA were more likely to be willing to fly in autonomous aircraft than participants in Germany and France, while participants in the age range of 18–34 with a high level of education displayed a positive attitude toward the idea of flying in a pilotless aircraft [59].

Molesworth and Koo [60] and Rice [61] agree that the familiarisation and prior knowledge of the population is a significant factor explaining willingness to fly in pilotless aircraft. Furthermore, Molesworth and Koo (2016) list enthusiasm for new technologies, age, educational level, and a potential enjoyable facet as the aspects that influence people's willingness to accept and travel by remote pilot aircraft. However, the crucial factor is trust.

Research performed between 2003 and 2015 concluded that the willingness to fly in pilotless aircraft had increased in the U.S [62]. It is agreed that customers prefer SPA than totally automated aircrafts; nonetheless, their enthusiasm for SPA does not stay the same when they are offered the traditional two pilot airliner as an alternative [48].

2.5. Research Methods Applied to Studies of Public Acceptance of SPA

Schmid and Stanton [56] performed a review of the current state of SPA and reduced-crew operation (RCO) in commercial aviation using 75 documents. Their conclusions led them to suggest that pilot's health monitoring systems have further scope for deeper research, whilst system protection is satisfactory reliable. Furthermore, they consider it necessary to integrate other approaches relevant to automation into the research field to make automated aviation more attractive. Stanton et al. [50] and Matessa et al. [63] conclude that acceptance by industry and the public are pivotal elements in the innovation network evolution of SPA and RCO.

Stewart and Harris [64] employed a mixed methods approach that engaged 117 UK citizens to explore their attitudes toward single-piloted operation (SPO). The state of the pilot, trust in technology, ticket price, and airline reputation were among the most central features of public acceptance. Correspondingly, [49] found that airline reputation, passengers' knowledge regarding SPO, social pressure, the safety track record of SPO over time, flight duration, urgency to travel, and ticket price are factors that influence public perceptions of SPO. Furthermore, their concerns were associated with safety matters.

The work of Kioulepoglou and Makris [49] was one of the few papers focused on the public acceptance of SPO. They supported their literature review discussion using 31 papers published between 1994 and 2017. Overall, 45% (14) of papers used qualitative approaches and one third used quantitative methods. Figure 2 shows the complete distribution of sources. From another perspective, the expected benefits of SPO prevails as the most explored topic between the sources involved. This coincides with [65,66]. The perception of SPO is in third place, with less than half of the top themes, as Figure 3 shows.

Research Gap

The public acceptance of SPA and willingness to fly must first be understood by the different stakeholders involved [67,68]. Otherwise, the risk of failure for unmanned aircraft technologies in financial and economic terms would be extremely high [69]. Public acceptance of new technologies not only depends on the diverse end-users' propensity to use them, but also on a complex network of interactions among policymakers and commercial benefits [70], as can be inferred from the rejection of the FAA reauthorization bill in 2017 discussed earlier in this review. Culture, values, and beliefs are variables that can affect acceptance of new technologies [19]. SPA applications in commercial aviation seem to be limited [64]. Thus, limited research has been conducted on single-pilot operation (SPO), and even less attention has been given to the public's attitude towards it [49]. Research on public attitudes toward autonomous transport has been centred on the demand and adoption of unmanned vehicles in public transportation, as well as on the examination of their benefits and problems [49,65,66].

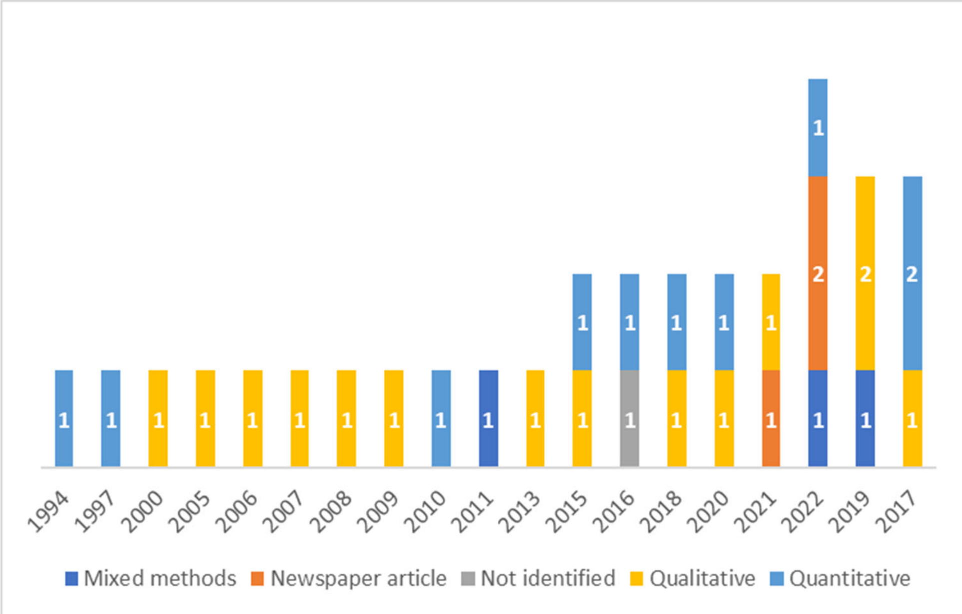

Figure 2. Number of used sources classified by research approach (adapted from [49]).

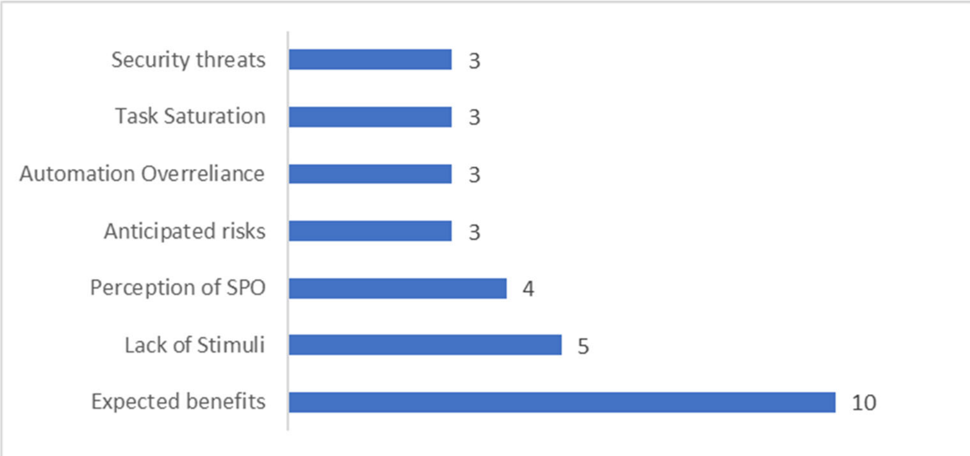

Figure 3. Number of papers classified by main topic (adapted from [49]).

Solid evidence has been revealed about the current gaps in SPA and hydrogen technologies applied in aviation. This justifies further research into the public acceptance of new aviation technologies that help to create a path which could bridge the gap between relevant but just inventions into innovative services such as HEART, whose application is designed for regional and sub-regional markets. In other words, research should seek to connect the gap between niche and large markets [16,17].

2.6. Technology Acceptance and Diffusion of Innovation

The public acceptance research herein relates to the intersection of technology acceptance models (TAMs) and the diffusion of innovation theory (DIT). Technology acceptance models (TAMs) are the preferred frameworks used by researchers to predict user acceptance of technologies [71]. Furthermore, TAMs have been used to examine disruptive technologies applied to different types of transport. DIT explains that a new technology goes through stages of adoption by different populations who participate in or begin using the new idea [72].

2.7. The HEART Project: Small Aircraft Using Hydrogen Electric

The UK-based project HEART (Hydrogen Electric and Automated Regional Transportation) aims to develop a novel business model in aviation based on hydrogen-fuel-cell-powered, partially automated aeroplanes carrying 9-to-19 passengers under single-pilot regulations (e.g., FAA FAR Part 135 CATO) [73]. Following the implementation of the Equality Act (Equality Act Guidance) [74], there is a growing expectation for public services to accommodate a wide range of diverse population needs. As part of the HEART project, public opinion was addressed to understand the potential of novel hydrogen–electric technology and aircraft automation and the key issues underlying acceptance, such as inclusion. The operating model for HEART is quite different to the conventional airline model and allows the more convenient selections of journeys and shorter overall journey times due to high-frequency operation and optimised point-to-point logistics. This may impact terminal operations, pre-booked services, and airport retail services. As such, public opinion issues relate to whether passengers would trust these operations of hydrogen aircraft and whether they would use them frequently and pay for convenience or carbon reduction.

This study aims to provide new evidence on the determinants of acceptance of a novel, hydrogen-based aviation service. In particular, the research questions of the study are as follows:

- Would travellers use the proposed service and if so, how frequently?
- What are the determinants of travellers' intentions to use the proposed service?
- What is the traveller's lived experience of air travel, in general, and how does it relate to the proposed HEART model?

To address these questions, a mixed methods (quantitative and qualitative) study has was conducted using data collected through interviews and public focus groups and a national public survey in Scotland. This constitutes the focus implementation area of the HEART project. The basis of the methodology is User-centred Ecological Interface Design, (UCEID). This combines elements of ecological, user-centred design with design for the inclusion of the widest capability range in the population [74,75]. The reported work represents a study using a multi-convergent methodology. This study integrates findings from a national survey, a literature review, and qualitative investigations, including interviews and focus groups conducted in two locations—one urban and one on an island—within Scotland.

3. Materials and Methods

The initial qualitative research stage aimed to identify public-facing issues and areas of priority for industry experts within the project consortium. These included airlines, autonomous flight specialists, hydrogen and technology specialists, architects, aircraft Original Equipment Manufacturers (OEMs), and airport operators, sampled using opportunistic methods. The research framework of the study is shown in Figure 4 so that readers can quickly grasp the research.

Some were consortium members and others were from external agencies. Following a series of workshops and interviews with these stakeholders, qualitative data were collected and analysed using a thematic analysis technique and recoded following iterative review. The results are shown in Figure 5. There were 14 main thematic priorities identified. These priorities helped identify emerging issues, which were the basis for online interviews, focus groups, and workshops with industry specialists and consortium partners). The issues that emerged from the qualitative data can be summarised as follows:

- **Lack of public understanding**: concerns operational issues that stem from a potential for a public lack of information or understanding regarding the novel technological and service issues of HEART as a future aviation model.
- **Civil Aviation Authority (CAA) regulations and certification**: the emerging themes on this topic include passenger familiarity with CAA regulations and certification, and their importance, as well as how this information is communicated to them.
- **Inclusion**: Theme issues regarding inclusion include understanding age groups that are more likely to use a travel app tailored to the HEART service; willingness to switch to app-based booking; the social inclusion of green travel options; the purpose of the journey; the demographics of passengers; passengers with restricted movement (PRM) and their challenges; and the impact of having no toilet on board the aircraft.
- **Climate change**: The issues regarding climate change include understanding the importance to passengers of reducing their carbon emissions when flying and importance of having green travel options available as part of the door-to-door journey.
- **Scheduling**: The perceived issues included the importance of timetables and the frequency of flights, as well as the impact of better scheduling and flexible booking.
- **Marketing and behavioural change**: Marketing campaigns would be key to changing current travel behaviour and showing the HEART network as an attractive alternative. Passenger experience may be dependent upon regular updates to passengers, minimal delays, and ease of connections.
- **Passenger experience**: issues regarding passenger experience also included understanding of hydrogen electric technology and single-pilot automated operations; passenger concerns regarding safety; the importance of seating areas, comfort, cleanliness and reliability; and passengers' expectations regarding transfers and baggage handling.
- **Airport design and operating model**: HEART was quite different to conventional airline models and allowed more convenient and flexible selections of journeys. The public-facing issues regarding the operating model mainly concern passengers' experience.
- **Price**: this involved whether price would influence passengers' choice to fly over other modes of transport, and how much passengers were willing to pay for this service.
- **Convenience and journey purpose**: The public-facing issues included willingness to switch to air travel and the convenience of nearby airports. For many, flying was seen as a necessity and lifeline. People depended on flying for work, reaching the nearest hospitals, accessing cities and airports, and meeting friends and families, as well as for leisure purposes.
- **Perceived safety**: It was anticipated that there would be scepticism associated with the use of hydrogen-fuelled aircraft and there were concerns about public-facing terminology regarding automation with the use of single pilots. For example, it was expected that people would be concerned about how effective the ground-based pilot support systems could be and whether hydrogen can be stored safely.
- **Political barriers**: These issues were expected from local people, environmentalists of all parties, and unions. However, this new aviation model has potential to reopen connectivity, including for people who would otherwise not have considered travelling. The enhancement of connectivity can also create an opportunity for economic development.

This thematic qualitative recoding was used as the basis for developing the questionnaire of the HEART national survey of the public in Scotland. This survey was constructed on the basis of demographics, stated preferences, attitudes, personality traits, and constructs stemming from the theory of diffusion of innovation and technology adoption models [72,76], and it included direct cost comparison examples. The public survey was carried out at the same time as a series of public focus groups addressing the same coding framework and incorporating opportunities to use the HEART "Mobilleo" App, a mobility-as-a-service app to be used for through travel bookings. The data from the survey were initially collated in the form of descriptive statistics and further analysed through extensive discrete-choice modelling [77]. The goal of the analysis of the survey data was to identify the factors affecting the likelihood and strength of the tendency to use the proposed HEART service, as well as the expected frequency of use of the HEART service.

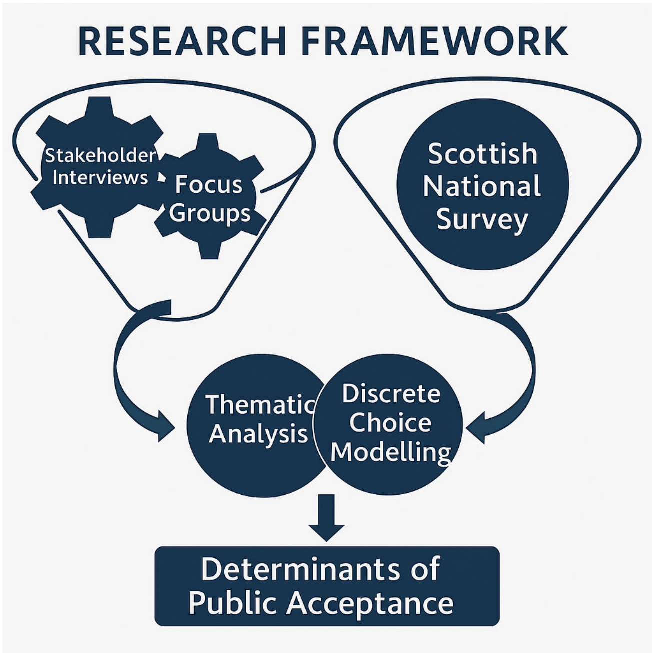

Figure 4. Research framework of the study.

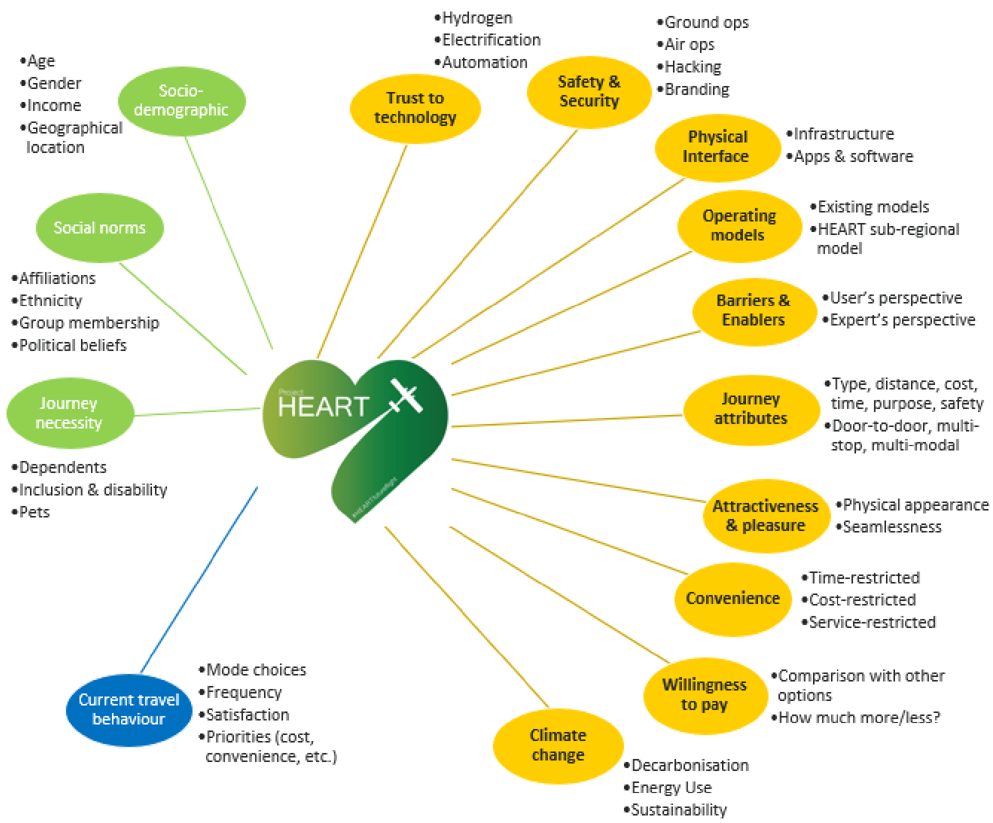

Figure 5. The mapping of priorities from the literature and consortium interviews and workshops.

3.1. Stakeholder Feedback

In response to the qualitative thematic analysis, the stakeholder and consortium responses focused on benefits and the importance of demographics. Stakeholders were sampled by availability and included industry and consortium partners, such as Highlands and Islands Airports Limited (HIAL) and Ex-CAA representatives. The HEART model could offer additional benefits for remote parts of Scotland and islands. This alternative mode of transport would be a cleaner and quicker option compared to current aviation, car, or ferry journeys. It was anticipated that engine electrification and hydrogen would be acceptable among the people from the islands who aspired to nurture their environment. However, there could be demographic differences between the islands, who are currently the prime users of aviation, versus the central belt of mainland Scotland. Other sociodemographic factors were clearly relevant, such as income, gender, age, location, disabilities, and health. The service was designed to be scalable to other UK regions. These factors and their associated causality were expected to be revealed by a public survey and statistical modelling and contextualised by the qualitative findings.

3.2. Focus Groups

Qualitative data were collected through three public focus group workshops, which were conducted in Scotland upon institutional ethical approval. The first took place in Kirkwall, Orkney, in November 2021 and had 13 participants. The Orkney Islands were selected for the first workshop due to the familiarity of the local population with island issues, including the production and use of "green" hydrogen [78]. The remaining workshops took place in Edinburgh in December 2021, each consisting of 11 participants. To recruit participants, the project disseminated calls for interest on social media internet sites, describing the focus group opportunity. Participants consisted of a mixture of local citizens, local university attendees, and those with previous interest in aviation or low-carbon transport. They represented different age strata and a balanced distribution in terms of gender. The workshops presented key facts of the project HEART (background, introduction to proposed technology), initiating discussion on the key points of this developing service. In addition, through a set of storyboards, all the successive stages of a door-to-door trip based on hydrogen aviation services were illustrated (Figure 6). With consent, each workshop was video- and voice-recorded. The recorded sessions were then transcribed for thematic coding and analysis.

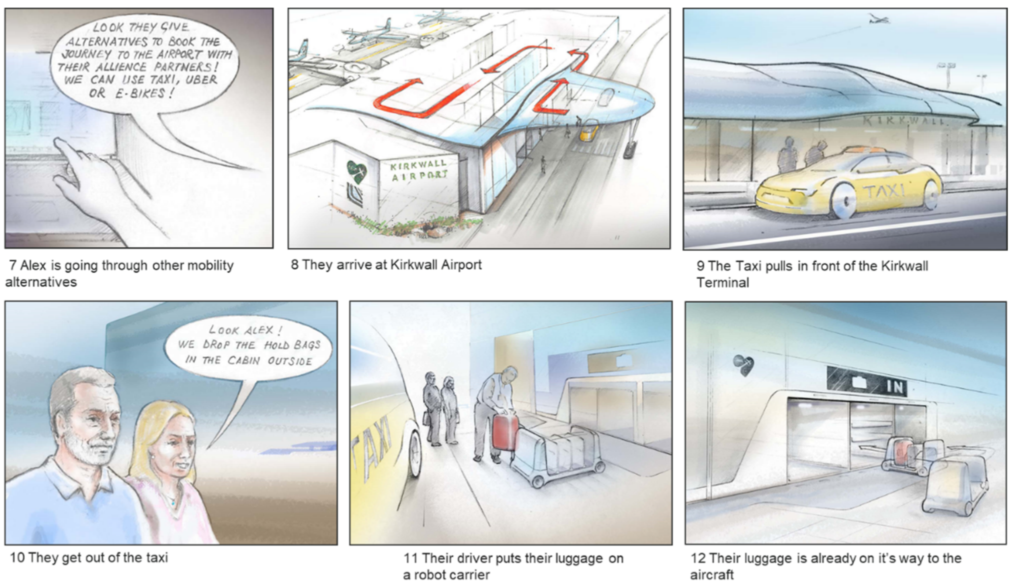

Figure 6. Storyboards used in focus group workshops and in the public survey of HEART.

3.3. Public Survey

In parallel with the focus groups, quantitative data were collected through an online survey of public opinion. The latter was carried out on the Scottish population using a quota-based, stratified sampling approach. Specifically, response panels of a commercial survey platform were obtained, which allowed us to recruit a representative sample of the population in terms of key sociodemographic characteristics, specifically, age, gender, and household income. The survey was live from the 8th of December 2021 to the 31st of December 2021. A total of 1029 responses were collected. The ratio of males (50%) to females (50%) was consistent with the gender distribution of the population, provided by the National Records of Scotland (M: 49%, F: 51%). The age distribution was also consistent with National Records for Scotland, with 52% of the respondents falling in the 45–60 age group. The age distribution of the sample is graphically compared to that of the Scottish population.

Cognitive testing for understandability was conducted to review the format and check data quality, questionnaire performance, speed, and the avoidance of invalid responses. A visual storyboard (see Figure 6) was included at the start of the survey to clarify and contextualise the passenger's experience of the main elements of the HEART service. This storyboard was developed to present only the key elements of the HEART service without predisposing the respondents' responses to the survey items.

The goal of the survey was to establish an understanding of perceptions and attitudes towards hydrogen–electric technology and aircraft automation amongst end-users. To that end, questions were targeted at capturing several dimensions of public acceptance, such as safety, trust, and eagerness to use the hydrogen service. The survey also enabled the collection of demographic traits, social contextual variables, behavioural characteristics, attitudes towards and details of willingness to pay, and stated preference data regarding what the public's priorities are in a normative context. All the questions were closed-ended, whereas the questions measuring perceptions and attitudes were formed using a 7-point Likert scale. The questionnaire received ethical and governance approval from the Edinburgh Napier University Ethical Panel.

4. Results

The complete survey results are summarised here by means of their relationship to the outcomes of the thematic analysis of the public focus group workshops, which were conducted in parallel to the public survey. This allows the results to be more concisely represented with respect to the relevant survey findings.

4.1. Survey and Workshop Evidence

The findings were grounded in previously identified thematic priorities, with new themes (nodes) emerging from the three workshops and integrated into the existing framework as they develop. The recoded top priorities were summarised under the following headings: 1. Operations (294 references); 2. Perception by Public (127 references); 3. Barriers & Enablers (80 references); 4. Safety & Security (76 references); 5. The Journey (41 references); 6. Business Case (28 references); and 7. Demographics (26 references). Each of these categories is examined in turn.

4.1.1. Summary of Operations (294 References)

Infrastructure Concerns

In terms of infrastructure, attendees were mostly concerned about the environmental impact of retrofitting or constructing new infrastructure as part of Project HEART. Overall, 29% of survey respondents were unsure about this, while 47% were less concerned about the effect HEART would have on the local area. However, the public survey revealed mixed opinions amongst users when it came to hydrogen storage. For example, 27% of users felt that hydrogen stored as a fuel at airports is safe, while 34% felt it was unsafe and 39% were inclined to neither agree nor disagree.

Seen to Be Green

Attendees expressed their views on how they perceive the environmental impact of HEART. Each group listed the reduction in CO_2 as a strength. The public was concerned about the environmental impact of the project and how any emissions created as a result of the project could be calculated.

Survey responses suggested that the public was less concerned about their own carbon impact. For example, when asked how important they considered their carbon footprint when choosing to travel by plane, 37% of respondents felt it was less important than cost, while 22% were uncertain, and 41% highlighted its importance. When asked about planning their travel for business, leisure, and necessity, 'environmental impact' was rated as being less important, regardless of the trip purpose.

Accessibility and Inclusive Design

Attendees were optimistic about the new HEART service being available but were concerned about access to other means of transport as part of the door-to-door journey in remote areas. Individuals were also concerned about the potential of HEART to become more accessible for everyone, irrespective of their capabilities.

Only 11% of respondents in the public survey identified as 'legally classified disabled'. Some 69% of survey respondents said they expect the HEART project to support passengers with restricted movement or families with young children.

Cost

The majority of attendees were positive regarding cost, and they could also see the economic benefit of the HEART service and the potential for market success. Attendees at the Orkney workshop expressed their interest in cheaper travel to and from the island as they described current air travel as expensive.

In the public survey, about 88% of the respondents considered the cost of the flight ticket as an important factor when planning their travel.

4.1.2. Summary of Perception by Public (127 References)

Attendees focused on how the HEART service will operate. For airport operations, attendees asked questions about baggage handling. There were also concerns raised about the security and fears about how baggage would be managed. This was also echoed in the public survey results, where almost half (49%) of the respondents were worried about losing their luggage at airports. Attendees could see the benefits of creating better connections and reducing their door-to-door journey time (61% of users).

Hydrogen

Workshop attendees showed interest in hydrogen and its source, but were unclear about its role in the service. It is likely that prominent historical hydrogen incidents would generate concern in some members of the public who fear hydrogen HEART planes pose the same risk of explosion. However, the focus group discussions found that some attendees were more concerned about new technology than the actual use of hydrogen. It was also evident that the younger members of the focus group were more accepting of new technologies compared to the older members of the group. This was consistent with the public survey findings, which showed that although familiarity with hydrogen as a fuel increased with age, older respondents were less likely to be early adopters of the HEART service compared to the younger ones. This suggests that acceptance may be influenced more by openness to innovation than by familiarity alone. Thus, younger generations have a better understanding of hydrogen technology through greater exposure to education, social media and online platforms, and therefore may be more accepting of new hydrogen technology [72].

4.1.3. Summary of Barriers & Enablers (80 References)

To summarise the barriers mentioned, attendees were concerned about emissions created as a result of possible new infrastructure for HEART and questioned the true zero operational carbon emissions as a result of the means of hydrogen production. Some attendees found the lower cost of HEART tickets and the costs involved to design and implement the service incompatible. It was clear that some struggled to visualise the operations of the service. The 350-mile range of the HEART planes was seen as a merit. Attendees saw the merit of door-to-door booking through the travel app, which was also presented in the workshop.

4.1.4. Summary of Safety & Security (76 References)

There was evidence of a lack of understanding of new terminal security systems, such as biometric facial recognition. There were also mixed responses about automation and the number of pilots on board the aircraft. This was also evident in the public survey, where nearly half (48%) of respondents agreed that a "pilot assisting automation makes flying safe", compared to 23% of respondents disagreeing with this statement, whereas 30% were somewhat unsure about this.

There were three key public fears highlighted in the focus group workshops. These included the following:

- Fear of hydrogen being dangerous;
- The transition from two pilots to one pilot operating the aircraft;
- The novel automated security system for baggage control and facial recognition.

This was apparently linked to passengers' familiarities with more commonly used aviation, which conventionally involves two pilots and typical security processes. Attendees were concerned about the procedures in place for secure baggage control and the risks imposed by a lack of scrutiny, such as restricted items passing security. Attendees were also concerned about the hacking of personal data and privacy.

These qualitative findings were also partially verified by the public survey. For example, 70% of respondents said they would be concerned about "no visible security controls at airports". There was support for strict security; 75% of respondents indicated that "extensive security and passport control are necessary at airports."

4.1.5. Summary of the Journey (41 References)

Attendees using the simulated travel app positively regarded the ability for through-booking, the specified CO_2 calculations for each trip, and being able to choose the quickest means of travel for their door-to-door journey.

In the survey data, respondents ranked highest price comparisons as the feature of a possible travel app. This was closely followed by features based around convenience, such as flight check-in (78%), live information updates (73%), a single payment option for the entire journey (62%), travel time comparisons (55%), accommodation booking (52%), customer service live chat (52%), and a single customer service for all booking inquiries (47%). Surprisingly, as shown in Figure 7, respondents were less interested in features such as green travel choices (26%) and CO_2 emission comparisons (35%).

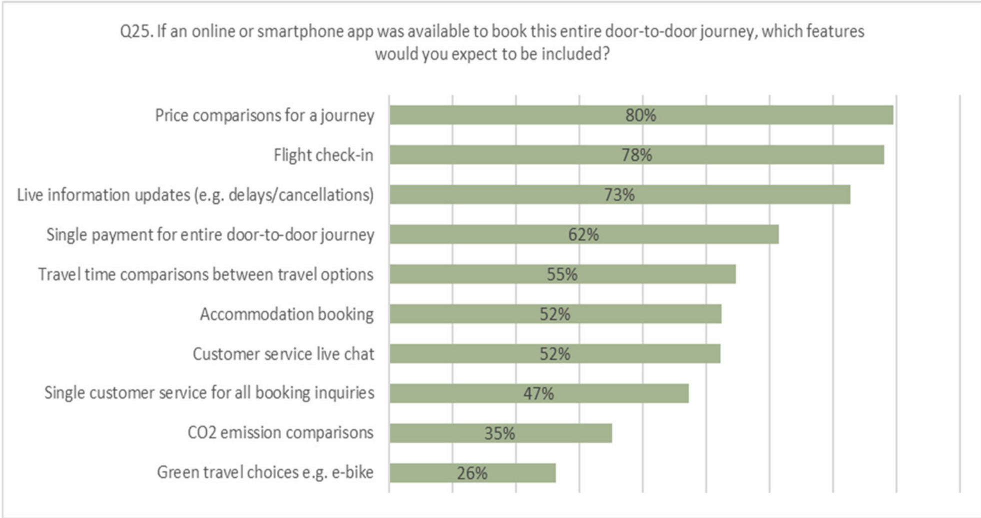

Figure 7. App features ranking.

Attendees pointed out how further benefits accrue as sustainable travel options increase. The app was also seen to benefit those living and working in remote areas and attendees were particularly interested in the potential for the app to reduce overall travel times by informing passengers in advance of wait times and check-in times. From group discussions, we found that attendees could see the HEART service as a convenient way to travel, particularly for those who lived on the islands or in remote locations across Scotland. They thought the service would lead to improved travel time, cheaper travel, reduced CO_2 emissions and, potentially, to more frequent flights. However, survey respondents focused on cost regardless of the journey's purpose. When respondents were asked to rank a list of items in order of preference, 'cost' was the most important item for travelling for either business (68%), leisure (84%), or necessity (87%). In contrast to the focus groups, the survey findings revealed that factors associated with intrinsic (personal) carbon impact were considered less important.

4.2. Statistical Modelling of Survey Data

The results from the survey present a clear snapshot of the public opinion in Scotland towards a HEART-type service. The survey also enabled the collection of demographic traits, social contextual variables, behavioural characteristics, attitudes towards the service, and details of willingness to pay, and also stated preference data regarding what the public's priorities are in a normative context. Additional items regarding personality types and disability were collected, but these were omitted from the statistical analysis to reduce complexity and retain the clarity of the findings.

4.2.1. Survey Results and Statistical Analysis

The descriptive analysis of the survey items, while enlightening, does not give enough information to allow strong inferences regarding the factors determining some aspects of acceptance, such as the following:

- How likely are people to use the hydrogen aviation service, as presented?
- How frequently would respondents use the hydrogen aviation service, as presented?

Unobserved Heterogeneity and Statistical Methods

To identify the factors that may determine the public acceptance of hydrogen aviation, two key dimensions of acceptance were statistically modelled using data from the corresponding survey questions: (i) public propensity to use HEART; and (ii) the frequency of the anticipated use of the HEART service for different trip purposes.

Clearly, some combinations of demographics, social context variables, and stated preferences underly each normative independent variable (IV) in the survey. Traditionally, some form of regression or factor analysis might support limited inference. Some regression-style discrete-choice approaches, such as logit or probit models, can be used when item responses are binary or ordered. These modelling approaches enable researchers to investigate discrete outcomes (dependent variables or DVs) associated with specific elements within the data.

However, survey-based perceptual data typically suffer from unobserved heterogeneity, i.e., the impact of unobserved factors that may be encapsulated in the impact of the factors observed [77,79]. The role of unobserved heterogeneity in eliciting reliable statistical inferences may be even more pronounced when public attitudes towards emerging technologies are examined, where the individuals may not have actual experience of the technology of interest [80,81]. To counteract the effect of unobserved heterogeneity, random-parameter ordered probit models were estimated, which incorporate allowances for heterogeneity in the means of random parameters that contribute to regression. The random parameters allow the parameter estimates of the IVs to vary across the respondents, thus enabling the heterogeneity to be revealed and eventually contributing towards a richer and more accurate picture of the possible causality behind the specific research questions. More details on the statistical formulation of the random-parameter ordered probit models can be found in the textbook of Washington et al. (2020) [77].

The subsuming research questions were identified as follows: (i) What would the propensity be to use the HEART service? (ii) What factors would affect the frequency of use for different trip purposes? These were operationalised to the following two survey items that were used as dependent variables (i.e., variables to be modelled and predicted): Q29 and Q35.

Focusing on the identification of the factors determining respondents' expected frequency to use HEART for different trip purposes, a bivariate probit model was developed. The specific modelling framework was selected, as we assumed that public perceptions relating to the future use of the hydrogen aviation service for different trip purposes trips may be conceptually interrelated. Such an interrelationship may result in the correlation of the error terms that correspond to the dependent variables representing the frequency of use for these trip purposes. The bivariate probit framework inherently assumes that the unobserved characteristics associated with the jointly modelled dependent variables are potentially correlated; hence, an additional parameter, the cross-equation error term, is also estimated along with the other model parameters.

The distributions (by gender and trip purpose) of the survey responses corresponding to the dependent variables of the models are presented in Figures 8 and 9.

Overall, from Figure 9, it is evident that approximately 10% of the sample would be among the first to use the hydrogen aviation service, whereas almost 8% of the sample seem reluctant (either "last to use" or "never") to use the service. This pattern of results is typical of responses to items from technological acceptance models [76,82] and the theory of the diffusion of innovation (TDI) [72], with a minority representing the extreme options (early adopters and non-adopters) and the majority of people going for the safer option in terms of price and familiarity [76].

Figure 8 shows that the majority of respondents would use the HEART service less than once a month, or not at all. The remainder would use the service at least once a month. Over 10% would use it frequently, at least once a week. At least half of the respondents would use the service less than once a year or never when travelling for either business or leisure. Among both males and females, the service is more likely to be used for leisure purposes and less likely to be used for business purposes. This pattern of results is typical of responses to items from technological acceptance models (TAMs), with a minority representing the extremes. A majority of people option for the safer option in price and peer comparison. However, even the negative two options only attract 8% of responses on average. Usually, this is linked to age; for example, older generations are less likely to adopt new technologies and technically able generations are more likely to adopt them [74,83].

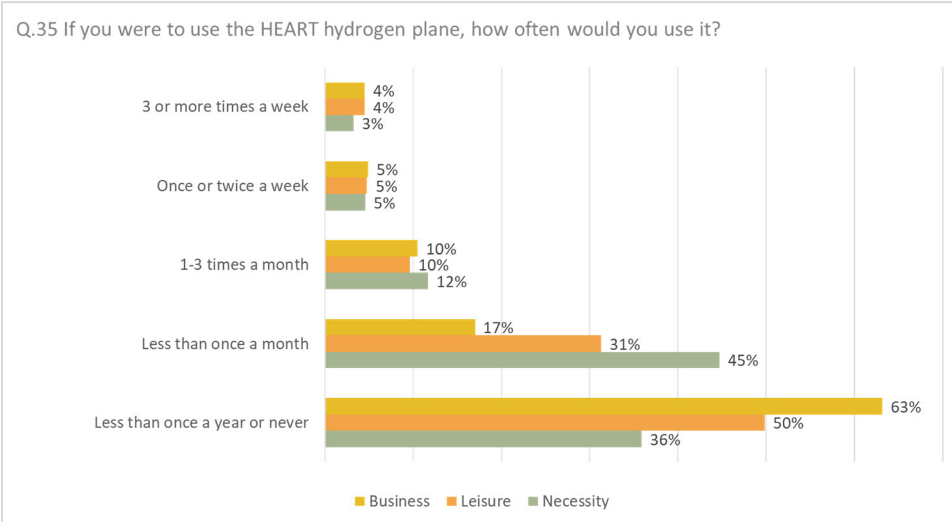

Figure 8. Frequency of using the HEART service by age, gender, and trip purpose.

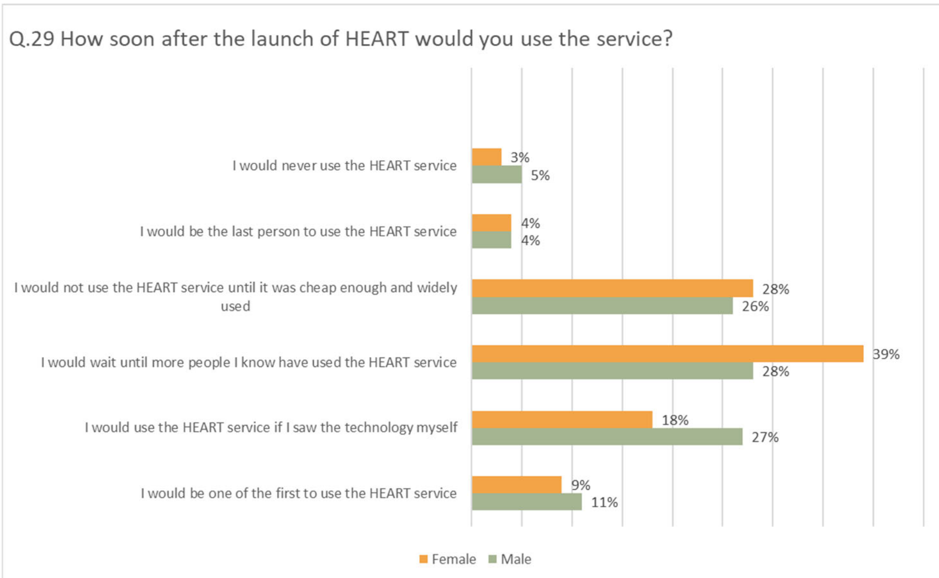

Figure 9. Propensity to use the HEART service by gender.

4.2.2. Survey Modelling: Propensity to Use

As shown in Figure 9, the Likert scale question capturing respondents' propensity to use the service had six outcomes. To gain more clear and distinct insights into the groups of potential adopters, the outcomes were merged into three discrete alternatives, which constituted the dependent variable of the model: (i) early adopters; late adopters; and non-adopters. The merger process was designed to reflect the optimal modelling setup, ensuring alignment with the distribution of the dependent variable while maintaining compatibility with the TAM model without losing key information. The summary results of the random-parameter ordered probit model with heterogeneity in the means (RPOPHM) are presented in Table 1, whereas the full modelling results are provided in Table A2 of Appendix A. A positive coefficient indicates an increase in the propensity to use the service, whereas a negative coefficient indicates a decrease in the same factor. Full descriptive statistics of the key variables included in the model can be found in Table A1 of Appendix A.

Table 1. Summary of effects for propensity to use HEART.

Variable	Early Adopter Probability
Fixed Parameters	
Age (18–29; 30–44; 45–60; older than 60)	↓
Annual household income (less than £15,599; 15,600 to 25,999; 26,000 to 36,399; 36,400 to 51,999; 52,000 or more)	↑
Area of residence (1 if urban, 0 otherwise)	↑↑
Flying rarely (1 if the respondent travels by plane less than once a year or never, 0 otherwise)	↓↓↓
Regular coach trips (1 if the respondent travels by coach at least once a month or more, 0 otherwise)	↑↑
Frequent necessity trips during COVID-19 (1 if the respondent travels for necessity at least once a week or more, 0 otherwise)	↓↓↓
Importance of carbon footprint when traveling by plane (1: Not at all important–7: Extremely important)	↑
Level of agreement with the statement "Pilot automation makes flying safe" (1: Strongly disagree–7: Strongly agree)	↑↑
Level of agreement with the statement "The distance to get to the plane is too long in airports" (1: Strongly disagree–7: Strongly agree)	↑
Level of agreement with the statement "I expect HEART planes to be noisy and to vibrate" (1: Strongly disagree–7: Strongly agree)	↓
Level of agreement with the statement "I tend to worry about losing my luggage when I travel by plane" (1: Strongly disagree–7: Strongly agree)	↓
Level of agreement with the statement "I expect toilet facilities on board the plane no matter how long the journey is" (1: Strongly disagree–7: Strongly agree)	↓
Importance of booking everything in one go with HEART (1: Not at all important–7: Extremely important)	↑
Random Parameters	
Requiring assistance in everyday life (1: Not at all affected–7: Extremely affected)	↑↑
Business area (1 if managerial, administrative or professional, 0 otherwise)	↓
Regular business trips during COVID-19 (1 if the respondent traveled for business at least once a month or more, 0 otherwise)	↓
Business area (1 if skilled manual worker, 0 otherwise)	↑↑↑
Level of agreement with the statement "I would be concerned about the effect HEART would have on the local area e.g., environment and economy" (1: Strongly disagree–7: Strongly agree)	↓
Gender (1 if male, 0 otherwise)	↓↓↓

Table key: "↑" or "↓" denote a variable with a significantly positive or negative parameter, respectively. The number of arrows, regardless of direction, correspond to the strength of marginal effects, where: ↑ = 0.000–0.029; ↑↑ = 0.030–0.059; ↑↑↑ = >0.060. The same strengths are valid for downward arrows.

A summary of the effects of the key independent variables for *propensity to use HEART* is shown in Table 1. Only statistically significant items are shown, and the direction and strength of the effect are indicated by the coloured arrows. An upward (green) arrow indicates a higher likelihood to be an early adopter, whereas a downward (red) arrow represents a higher likelihood to be a non-adopter of the HEART service, and at the same time, a lower likelihood of being an early adopter of HEART. For example, for the binary variable "regular coach trips", there is a strong positive relationship with the outcome of the dependent variable, representing the early adopters of HEART. Hence, it can be inferred that if travellers use coaches once a month or more, they are more likely to be earlier adopters of HEART.

Overall, Table 1 shows that a number of factors significantly affected the respondents' propensity to use the HEART service. The key independent variables included demographics, such as age, gender, area of residence, and the business area of the individual. Socioeconomic factors and travel behaviour variables included household income, mode of travel, and frequency of travel for different trip purposes (i.e., business, necessity, or leisure). An important group of attitudinal variables in the HEART context were also identified as key determinants of propensity to use the service, including travel preferences, such as ease of booking, tolerance of carbon footprint, concern about the environment, and several perceived properties of the journey; these properties refer to reliability, carbon footprint, comfort, safety and security, ability to connect (physical), the loss of luggage, and whether the plane is equipped with a toilet.

4.2.3. Survey Modelling: Frequency of Use

The second dependent variable that was analysed was Q35, *frequency of use*. This was performed in order to assess the strength of motivations behind the propensity to use. As shown in Figure 8, the majority of respondents would use the HEART service less than once a month or not at all. The remainder would use the HEART service at least once a month. Over 50% would use it frequently, from 3 times per month to 3 times a week. At least half of the people would use the HEART service less than once a year or never when travelling for business or leisure. The HEART service is more likely to be used for leisure and necessity.

The summary results of the Bivariate Ordered Probit are provided in Table 2, whereas full modelling results are provided in Table A3. Following the same logic regarding the propensity to use, the outcomes of the frequency-to-use dependent variable were merged into three major categories for the purposes of statistical modelling: (i) at least once a month or more (i.e., 3 or more times a week or once or twice a week or 1–3 times a month); (ii) less than once a month but at least once a year; and (iii) less than once a year or never. Due to partial or missing information for some independent variables, 966 observations were used for the estimation of the frequency-of-use model. Only business and leisure trip purposes were used in the statistical modelling, on the basis that they enabled optimal bivariate modelling. It should be noted that the frequency of using HEART for business and leisure was jointly modelled through a bivariate framework to account for the potential interdependencies that may underpin public perceptions of mode choice for different trip purposes.

Table 2 shows that a number of factors significantly affected the respondents' frequency to use the HEART service. The independent variables with observable influence on frequency included demographics such as age gender, need for assistance, and area of residence, while socioeconomic variables included household income. An important group of attitudinal and behavioural variables in the HEART context includes travel choices and attitudes such as mode of travel, the tolerance of carbon footprint, travel purposes for business, necessity, or leisure purposes, and properties of the journey, such as reliability, safety, and security.

Table 2. Summary of effects for frequency to use HEART.

Variable	Business Trips Probability for Using HEART at Least Once a Month or More	Leisure Trips Probability for Using HEART at Least Once a Month or More
Gender (1 if male, 0 otherwise)	↑↑	↑↑
Age (18–29; 30–44; 45–60; older than 60)	↓↓↓	↓↓
Annual household income (less than £15,599; 15,600 to 25,999; 26,000 to 36,399; 36,400 to 51,999; 52,000 or more)	↑	–
High annual household income (1 if greater than £36,400, 0 otherwise)	–	↑↑
Area of residence (1 if urban, 0 otherwise)	↑	–
Requiring assistance in everyday life (1: Not at all affected–7: Extremely affected)	↑	–
Personality trait (1 if openness, 0 otherwise)	–	↑↑↑
Train use for business trips (1 if respondent uses train mainly for business trips, 0 otherwise)	↑↑↑	–
Car use for business trips (1 if respondent uses car mainly for business trips, 0 otherwise)	↑↑↑	–
Car use for leisure trips (1 if respondent uses car mainly for leisure trips, 0 otherwise)	–	↑
Business trips reduction due COVID-19 (1 if frequency of business trips during COVID is lower than before COVID, 0 otherwise)	↑↑↑	–
Reliability for business trips (1 if reliability is among the three lowest-ranking factors of importance for trip planning, 0 otherwise)	↑↑	–
Safety/security for leisure trips (1 if safety/security is among the three highest-ranking factors of importance for trip planning, 0 otherwise)	–	↑↑
Connections for business trips (1 if the number of required connections is among the three highest-ranking factors of importance for trip planning, 0 otherwise)	↑↑↑	–
Importance of carbon footprint when traveling by plane (1: Not at all important–7: Extremely important)	↑	↑
Importance of retail & duty free access when traveling by plane (1: Not at all important–7: Extremely important)	↑	↑
Familiarity with hydrogen (1: Not at all familiar–7: Extremely familiar)	↑	↑
Level of agreement with the statement “Pilot automation makes flying safe” (1: Strongly disagree–7: Strongly agree)	–	↑
Level of agreement with the statement “I expect toilet facilities on board the plane no matter how long the journey is” (1: Strongly disagree–7: Strongly agree)	↓	↓
Importance of flight cost with HEART (1: Not at all important–7: Extremely important)	↓↓↓	–
Level of agreement with the statement “I would be concerned about the effect HEART would have on the local area e.g., environment and economy” (1: Strongly disagree–7: Strongly agree)	–	↓

Table key: “↑” or “↓” denote a variable with a significantly positive or negative parameter, respectively, “–” indicate that a variable was trialed as a potential explanatory factor, however, the variable’s effect was insignificant. The number of arrows, regardless of direction, correspond to the strength of marginal effects, where: ↑ = 0.000–0.029; ↑↑ = 0.030–0.059; ↑↑↑ = >0.060. The same strengths are valid for downward arrows.

4.2.4. Interpretative Summary of Modelling

Age and Gender

Gender was identified as a random parameter in the propensity-to-use model, which means there was a strong bias towards women to be early adopters of the HEART service, as presented (83% according to the mean and the standard deviation of the random-parameter distribution—see Table A2), although this effect was found to vary across the survey responses. Women were also more likely to be more frequent users of HEART for business or leisure. The reasons for this were unclear and may reflect a perception of the service as more physically or socially inclusive or may reflect a gender-based need for convenience and reduction in travel time. Attitudes towards social issues, such as climate change and social mindedness, are more prevalent in women [84]. In addition, greater necessity and responsibilities in home-making and care-giving is linked to time management [84], particularly in inclusive families. The proposed HEART service offers greater speed compared to alternatives, making it a potentially preferred choice, particularly for family households where time efficiency is crucial.

Older respondents were more likely to be non- or late adopters and the younger age groups were more likely to be early adopters. The younger age groups were more likely to be frequent users for business purposes and were fairly frequent users for leisure too. It seems likely that younger travellers were more positively orientated to the novelty of service. Older age groups may have a weaker tendency to embrace change and may have come from generations that expected breakdowns in novel innovative engineering services. The survey descriptives also suggest that they may also have avoided embracing extreme views regarding the adoption of technologies that they may not understand.

Income, Location, and Occupation

Those travellers who earned more (>GBP 36,400) were more likely to use the service and were also more likely to be frequent users for leisure. This suggests that they were either predisposed to fly or more likely to adopt an experimental aviation approach. Those who would use HEART for business were likely to be more frequent users, which may reflect their expectations of a reliable and quick service. However, those travellers on low incomes were less likely to use HEART frequently for business trips, which may reflect the nature of their responsibilities at work.

People who lived in urban rather than rural areas were more likely to adopt early and were likely to use more frequently for business. Business passengers are likely to be more familiar with transportation options and open to options presented in apps. Skilled manual workers demonstrated a strong inclination toward early adoption, likely driven by pre-existing travel needs and work-based travel strategies inherent to their roles. In contrast, those in managerial, administrative, or professional occupations showed a mild reluctance to adopt early, possibly reflecting a degree of conservatism in their choices and the lesser immediacy of travel necessities in their work. Skilled manual labourers understand and are receptive to new technology. It is possible that manual work involves more injuries, and HEART was seen as an opportunity to avoid lengthy, demanding road and ferry travel for therapy. It should be noted that both findings related to the impact of employment status require further investigation in the future, as both variables resulted in random parameters, highlighting the existence of mixed effects underlying and determining the travel choices of these groups.

Frequency of Travel

The modelling results offered several insights into how the characteristics of individuals' journeys were connected to the proposed HEART service, as presented to the potential users. For example, there was a strong tendency for those who flew rarely, if ever, to be late or non-adopters. Superficially, this may reflect a lack of urgency about possible use, but also could reflect differing journey types that may permit longer and more leisure-driven trips, such as visiting relatives or other leisure activities.

Frequent travellers during COVID-19 were less likely to be early adopters and more inclined to be late adopters of the HEART service. This behaviour likely reflects the critical nature of their journeys, which continued throughout the pandemic. These individuals value the reliability and ease of modality change offered by the HEART model. This is further supported by the strong association that was identified between frequent travel during COVID-19 and frequency of the use of HEART for business purposes, suggesting that such travellers already had established, adequate, and reliable travel methods in place. For example, they may be car users or have access to a car. HEART may also be perceived by some as more appropriate for business travel. Travellers who used cars for leisure were more likely to use the HEART service frequently for leisure trips, reflecting the willingness to pay more to increase convenience and significantly reduce the length of such travel, allowing for more time engaged in leisure activities.

Service Properties

Modelling reveals some positivity towards HEART, as presented. For example, those travellers valuing the capability to book travel on a mobility-as-a-service (MAA) travel app were slightly more likely to adopt early and less likely to be non-adopters, indicating that the door-to-door booking capability and the convenience of a one-stop-app for multimodal travel was appreciated. This presumably reflected the technology-aware individuals who were familiar with using mobile device apps for securing services and who may be urban business travellers.

Passengers who were concerned with how far to walk to get to the plane in airport terminals were more likely to use a HEART service, and those interested in retail and duty-free offerings also showed a greater tendency to be more frequent users of a HEART service for business or leisure, perhaps implying that HEART represented new duty-free and retail opportunities. Leisure passengers that were likely to be more frequent travellers also indicated that they strongly valued their safety and security, reflecting similar views to those expressed in the focus groups.

Some negative indications regarding HEART were that those with greater expectations of the service being noisy were more likely to be late or non-adopters, as were those concerned about the loss of luggage. This might be expected if a barrier towards use arose from their lack of knowledge of the new technologies in reality. Among those making regular business trips, travellers that were younger, more familiar with hydrogen, and favourably inclined towards automation were likely to adopt and were more likely to be frequent travellers for both business and leisure purposes. Those that rated the importance of carbon footprint highly also tended to be early adopters. This seemed to reflect greater acceptance by a younger, technology-orientated, and climate-aware population [84]. Those that were concerned about the effect on the locality were less likely to be frequent travellers for leisure. The personality traits most strongly associated with a tendency for frequent use of HEART for leisure only was openness, perhaps reflecting a predisposition to be open to new experiences of travel.

5. Discussion

5.1. Perception of Hydrogen as a Fuel

In the public survey, 63% of respondents said they were unfamiliar with hydrogen as a fuel, while 16% were unsure, and only 22% said they were familiar with it. When asked if they considered hydrogen to be a safe modern fuel for planes, there were mixed opinions, as 26% disagreed that it was safe, 36% agreed it was safe, and 39% were unsure. This confirms users' lack of understanding about hydrogen, as noted during the focus group discussions. Interestingly, nearly half of the respondents (48%) were inclined to believe hydrogen is a next-generation fuel, while a third of respondents (33%) were unsure.

Despite this, qualitative, survey, and statistical findings consistently indicated that hydrogen was not perceived as overly concerning or unsafe and did not provoke extreme opinions. Hydrogen featured in discussions of perceived safety and security, but this was alongside automation, baggage control, security in the terminal. Respondents were aware of safety issues, as these featured in focus group discussions. As many as 70% of survey respondents said they would be concerned about "no visible security controls at airports", although there was support for strict security as 75% of respondents indicated that extensive security and passport control were necessary at airports.

Of the small amounts (17%) of males who tended to be more likely to use the HEART service, early adopters were more likely to be familiar with hydrogen as a fuel technology. The survey descriptives also suggest that respondents may also have avoided extreme views regarding the adoption of technologies that they do not understand [85]. Hydrogen was seen as a means to lower carbon emissions in discussions of operations, suggesting that sustainability was appreciated but HEART was seen as having the potential for negative as well as positive lifestyle impacts [15–17]. Although, in general, this suggested that technology familiarity is related to a propensity to use HEART, this cannot be inferred from the modelling, which also does not explain women's attraction to the service.

5.2. Single-Pilot Operations

During the focus group discussions, it was noted that single-pilot operated services did not cause a concern. However, in the public survey, 74% of users felt it was important to have two pilots flying the plane, while a further 18% of respondents were unsure. These differences may have been related to focus group participants being more accepting of single-pilot operations due to familiarity with island aviation. Although regulations regarding sub-regional commercial aviation in the UK do not require two pilots, with scheduled services routinely carried out with single pilots, the HEART project proposes single-pilot operation in conjunction with automated flight systems to reduce pilot workload. Activities such as reacting to events and determining routes can involve pilots with only a monitoring role, while the automated system performs the complex tasks [86]. Single-pilot aircraft (SPA) applications in commercial aviation seem to be limited [64]. However, it is foreseen that SPA will have applications other than with military purposes in the mid-term [87]. The use of SPA in light applications such as air taxis and light cargo transportation is common in the air transport industry. Stewart and Harris [64] conclude, based on qualitative data generated in workshops, that aspects related to safety—such as trust in technology; the state of the pilot in terms of workload and health; and a reduction in the tariff—are crucial factors in efforts to encourage the willingness to fly in SPAs [64].

5.3. Technology Acceptance Model and Diffusion of Innovation

There was considerable evidence that data from the survey and modelling was consistent with the pattern that would be expected from the TAM and DIT model. The public survey offered more in-depth understanding of this, and it was found that 10% of users would be "one of the first to use the HEART service", while a third "would wait until more people have used the HEART service". Almost 8% of the sample seem reluctant (either "last to use" or "never") to use the service. These results are typically found using technological acceptance models and diffusion of innovation models [72,76], i.e., the majority of people opt for the safer option, but a minority will take some degree of risk. A small minority are expected to refuse to engage at all.

Modelling also revealed that older respondents were more likely to be non- or late adopters, while the younger age groups were more likely to be early adopters. The younger age groups were more likely to be frequent users for business, and were fairly frequent users for leisure too. It seems likely that younger travellers are more positively orientated to the novelty of service and its presentation as an app-led booking system. Travellers who saw their carbon footprint as important were more likely to adopt HEART early. Older age groups may have had a weaker tendency to embrace change and may have come from a generation that expected breakdowns in novel innovative engineering services [74]. This is consistent with the findings of the Traveller Needs and UK Capability Study (2015) [84]. This 10,000-respondent project classified traveller types. "Local Drivers" (24%) were partially characterised as retirees making low-milage local journeys. In contrast, "Progressive Metropolites" (14%) were technology-savvy young professionals, with significant amounts of personal and business travel experience who wanted to reduce their transport footprint [88]. It should be noted that up to 40% of aviation traffic to the Scottish Islands is the result of medical necessities for which there is no alternative due to logistics of cost and time [89]. The TAM and DIT theories and methods portray *perceived ease of use* and *perceived usefulness* by users as capable of predicting the willingness to use a new technology [26]. HEART measured perceptions of use and modelled correlates of use, as expressed in attitude and preference data. Some significant emerged issues for acceptance, although these were not all deemed significant from statistical modelling alone.

In contrast to the barriers identified during the workshop, attendees could see benefits. These included an improved travel experience through time savings, lower costs, reduced CO_2 emissions, more frequent services, and enhanced inclusivity for individuals with capability challenges. Smaller aircraft were seen as beneficial for higher travel frequency, better connections, and greater time saving. In the survey, 86% of respondents identified 'comfort and cleanliness' as an important feature (ranked third highest) of using the HEART service. It was also evident that there was uncertainty amongst users regarding noise and potential new working patterns. Focus groups predicted opposition from retail and saw the service as a threat of job losses, as well as a source of potential political opposition for airport automation.

Cost emerged as a pivotal issue, with respondents ranking price comparison as the most desirable feature in the travel app and assigning deprecating green travel and CO_2 emissions lower rankings. When respondents were asked to rank a list of items in order of preference, 'cost' was the most important item for travelling for either business (68%), leisure (84%), or necessity (87%). High-earning travellers were more likely to use the service and were also more likely to be frequent users for leisure. However, those travellers on low incomes were less likely to use HEART frequently for business trips.

Regarding the journey, travellers rating the importance of flight cost were less likely to use the service frequently for business. This suggests that non-business travellers were more cost-conscious. Those that valued cost little and were prepared or capable to pay more also had a tendency to be more frequent travellers for business, reflecting business users' ability to pay more from business travel accounts. Travellers who valued the importance to make connections while travelling for business were more likely to use HEART frequently for business, reflecting the need to travel to diverse locations requiring more travel stops. Frequent business users strongly rated the importance of reliability, reflecting the requirements for punctuality and need for certainty in business travel. Other travellers who considered reliability to be less important were less likely to use HEART for business trips, presumably having less concern about arrival times and haste.

Urban dwellers were more likely to adopt early and were likely to use a service more frequently for business. This is likely due to the greater exposure and availability of novel or internet-based services in urban environments. Frequent coach (and train) users were more likely to be earlier adopters of HEART, which may reflect the perceived importance of faster travel times and convenience for these individuals. This appears understandable if they carry over their tendency to travel to new offerings in the market. They may have developed reliable, adequate travel arrangements or may be constrained from flying by other factors such as distance from the airport, cost, the reduced availability of flights, or being close to the final destination. Train delays and missing connections may have been a contributing factor in recent years.

Travellers requiring assistance in everyday life showed a tendency to adopt early, with a slight tendency to use the service more frequently for business only. The groups needing assistance were likely to be used to assessing technology and travel options as a problem-solving requirement. This suggests that HEART was seen as more accessible by certain frequent business users, who only found travel difficult, rather than those travellers with more severe impairments.

However, those that valued the importance of toilets on board the aircraft were more likely to be late adopters. Travellers tending to require toilet provision on board the aircraft were less likely to be frequent users of HEART generally, reflecting doubts that there would be toilets on board the smaller planes. Those with expectations of toilets on board were less likely to be frequent passengers for either business or leisure, presumably revealing apprehension regarding flight without toilet facilities that could be related to disability, although this was mitigated by relatively short journey times. Despite short journeys, toilet use may be a hard barrier to usage as around 30–40% population require toilets within in 1–2 h [90]. It is accepted that 'perceived usefulness' in DIT models can be transferred between users of similar technologies, such as from current remote-piloted drone users to passengers of Urban Air Mobility (UAM). In the case of HEART, the Scottish location of the study provided access to participants and respondents who were likely to be more familiar with small-aircraft services to islands and small regional airports using small twin-engine aeroplanes such as the BN Islander of DH-6 Twin Otter, often with single-pilot operation.

6. Conclusions

A range of findings emerged concerning the technology, including its safety, environmental impact, and the personal implications of features associated with the novel service. Respondents had not experienced HEART technologies and recognised that they did not fully understand them. This may have manifested itself as negativity amongst some population elements, or as positive bias on the parts of others. This would also lead to patterns of results whereby responses were clustered around the mid-point choice in Likert scale questions, as occurred in the survey.

1. **Perceived novelty and affordability**: Respondents perceived HEART as a novel transportation service that they did not fully understand but viewed as affordable under some conditions and as offering promising travel opportunities. Key perceived benefits included speed, convenience, inclusion, and accessibility.
2. **Appeal across travel purposes**: Specific features of HEART—such as efficiency and ease of access—were recognised as particularly attractive by both business and leisure travellers. Both features increase the likelihood of using the HEART service more frequently, as shown by the results of the statistical models. This reflects potential appeal across a broad user base.
3. **Inclusion and accessibility**: HEART was widely seen as an inclusive service, accommodating individuals with varying degrees of physical, sensory, or cognitive impair-

ments. Approximately 70% of respondents expect the HEART project to support passengers with restricted movement or families with young children, particularly with door-to-door convenience and terminal support.

4. **Attitudes toward innovation**: Respondents showed a generally positive attitude toward technological innovations associated with HEART. Around 43% responded favourably to electric and hydrogen-powered propulsion systems, while 47% expressed approval of increased automation. The single-app booking system was also received positively by the majority of respondents, particularly for its potential to offer efficient price comparisons (80%) and seamless flight check-in (78%).
5. **Environmental and socioeconomic concerns**: Despite the overall positive sentiment, a notable portion of participants (approximately 35%) expressed hesitance or resistance to adopting HEART. Concerns were primarily environmental (e.g., noise, pollution), logistical (e.g., congestion, automated baggage systems), and economic (e.g., impact on local infrastructure or traditional services). Notably, the importance of flight cost was identified as a key factor with a pronounced negative impact, reducing the likelihood of using the HEART service by more than 0.06. These views likely stem from current perceptions of conventional aviation impacts on the environment and the economy rather than from the HEART concept itself. Further research will examine the UK-wide acceptance of the service and look at the aircraft, terminal, and through-booking application in more detail.
6. **Adoption potential dependent on awareness**: Adoption intent was closely tied to respondents' understanding of HEART's features. Among those who understood the system well, there was a clear tendency toward frequent use. However, lack of clarity or unfamiliarity led to the clustering of responses at the survey midpoint, indicating uncertainty or neutrality.

The qualitative and quantitative research reflected a specific time period and Scottish locations in 2021, just following the social effects of COVID-19. In particular, the survey only captured a snapshot of responses from a self-selected group in terms of familiarity with sub-regional aviation, and communications technology, who were working on a limited description of the HEART service. Hence, the results from both types of evidence can only be considered as indicative of summative, generalisable findings, as demonstrated by the differences observed between focus group outcomes, modelling, and survey data.

The discrete-choice modelling (random-parameter ordered probit with heterogeneity in means), while powerful and yielding a considerable number of statistically significant results, only used three outcome variables (as DVs), *propensity to use*, and *frequency of use* for business and leisure trips. This was due to the necessity of optimising the method for available computational power and analysis. Despite this, many significant causalities were identified, along with some indications of their strength. The large number of significant effects meant interpretation was by necessity truncated. This was due to the dominance of stronger effects.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data are partially contained within the article and available on request due to restrictions.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Descriptive statistics of key variables.

Variable	Mean or Percentage (%)	Standard Deviation
Age (18–29; 30–44; 45–60; older than 60)	2.681	1.109
Annual household income (less than GBP 15,599; 15,600 to 25,999; 26,000 to 36,399; 36,400 to 51,999; 52,000 or more)	2.989	1.398
Area of residence (1 if urban, 0 otherwise)	55.458%	-
Flying rarely (1 if the respondent travels by plane less than once a year or never, 0 otherwise)	62.002%	-
Regular coach trips (1 if the respondent travels by coach at least once a month or more, 0 otherwise)	15.938%	-
Frequent necessity trips during COVID-19 (1 if the respondent travels for necessity at least once a week or more, 0 otherwise)	36.929%	-
Importance of carbon footprint when travelling by plane (1: not at all important—7: extremely important)	4.050	1.786
Level of agreement with the statement “Pilot automation makes flying safe” (1: strongly disagree—7: strongly agree)	4.396	1.494
Level of agreement with the statement “The distance to get to the plane is too long in airports” (1: strongly disagree—7: strongly agree)	4.585	1.551
Level of agreement with the statement “I expect HEART planes to be noisy and to vibrate” (1: strongly disagree—7: strongly agree)	3.108	1.486
Level of agreement with the statement “I tend to worry about losing my luggage when I travel by plane” (1: strongly disagree—7: strongly agree)	4.307	1.719
Level of agreement with the statement “I expect toilet facilities on board the plane no matter how long the journey is” (1: strongly disagree—7: strongly agree)	5.595	1.587
Importance of booking everything in one go with HEART (1: not at all important—7: extremely important)	5.333	1.427
Requiring assistance in everyday life (1: not at all affected—7: extremely affected)	0.115	0.319
Business area (1 if managerial, administrative or professional, 0 otherwise)	34.893%	-
Regular business trips during COVID-19 (1 if the respondent travelled for business at least once a month or more, 0 otherwise)	28.086%	-
Business area (1 if skilled manual worker, 0 otherwise)	13.835%	-
Level of agreement with the statement “I would be concerned about the effect HEART would have on the local area e.g., environment and economy” (1: strongly disagree—7: strongly agree)	3.470	1.544
Gender (1 if male, 0 otherwise)	49.368%	-
Familiarity with hydrogen (1: not at all familiar—7: Extremely familiar)	2.033	1.646

Table A2. RPOPHM model on propensity to use.

Variable	Parameter	*t*-Stat	*p*-Value
Fixed Parameters			
Constant	−1.410	−3.67	0.000
Age (18–29; 30–44; 45–60; older than 60)	−0.136	−2.47	0.014
Annual household income (less than GBP 15,599; 15,600 to 25,999; 26,000 to 36,399; 36,400 to 51,999; 52,000 or more)	0.140	3.25	0.001
Area of residence (1 if urban, 0 otherwise)	0.213	2.01	0.044
Flying rarely (1 if the respondent travels by plane less than once a year or never, 0 otherwise)	−0.872	−7.29	0.000
Regular coach trips (1 if the respondent travels by coach at least once a month or more, 0 otherwise)	0.270	1.76	0.079
Frequent necessity trips during COVID-19 (1 if the respondent travels for necessity at least once a week or more, 0 otherwise)	−0.412	−3.67	0.000
Importance of carbon footprint when travelling by plane (1: not at all important—7: extremely important)	0.070	2.19	0.029
Level of agreement with the statement "Pilot automation makes flying safe" (1: strongly disagree—7: strongly agree)	0.241	5.96	0.000
Level of agreement with the statement "The distance to get to the plane is too long in airports" (1: strongly disagree—7: strongly agree)	0.089	2.43	0.015
Level of agreement with the statement "I expect HEART planes to be noisy and to vibrate" (1: strongly disagree—7: strongly agree)	−0.124	−2.77	0.006
Level of agreement with the statement " I tend to worry about losing my luggage when I travel by plane" (1: strongly disagree—7: strongly agree)	−0.083	−2.46	0.014
Level of agreement with the statement "I expect toilet facilities on board the plane no matter how long the journey is" (1: strongly disagree—7: strongly agree)	−0.130	−3.76	0.000
Importance of booking everything in one go with HEART (1: not at all important—7: extremely important)	0.130	3.21	0.001
Means of random parameters			
Requiring assistance in everyday life (1: not at all affected—7: extremely affected)	0.303	1.74	0.081
Business area (1 if managerial, administrative or professional, 0 otherwise)	−0.051	−0.41	0.680
Regular business trips during COVID-19 (1 if the respondent travelled for business at least once a month or more, 0 otherwise)	−0.160	−0.84	0.400
Business area (1 if skilled manual worker, 0 otherwise)	0.347	2.08	0.037
Level of agreement with the statement "I would be concerned about the effect Heart would have on the local area e.g., environment and economy" (1: strongly disagree—7: strongly agree)	−0.084	−2.04	0.042
Gender (1 if male, 0 otherwise)	−0.408	−2.54	0.011
Standard deviations of random parameters			
Requiring assistance in everyday life (1: not at all affected—7: extremely affected)	1.209	7.13	0.000
Business area (1 if managerial, administrative or professional, 0 otherwise)	0.844	8.80	0.000
Regular business trips during COVID-19 (1 if the respondent travelled for business at least once a month or more, 0 otherwise)	1.248	10.09	0.000
Business area (1 if skilled manual worker, 0 otherwise)	0.907	5.83	0.000
Level of agreement with the statement "I would be concerned about the effect Heart would have on the local area e.g., environment and economy" (1: strongly disagree—7: strongly agree)	0.248	13.86	0.000
Gender (1 if male, 0 otherwise)	0.435	5.82	0.000

Table A2. *Cont.*

Variable	Parameter	*t*-Stat	*p*-Value
Heterogeneity in the means of random parameters			
Regular business trips during COVID-19: Familiarity with hydrogen (1: not at all familiar—7: Extremely familiar)	0.270	4.11	0.000
Gender (male): familiarity with hydrogen (1: not at all familiar—7: Extremely familiar)	0.295	5.66	0.000
Threshold (μ)	3.668	21.26	0.000
Distributional effects of random parameters		**Non-adopters**	**Early adopters**
Requiring assistance in everyday life (1: not at all affected—7: extremely affected)		40.11%	59.89%
Business area (1 if managerial, administrative, or professional, 0 otherwise)		52.41%	47.59%
Regular business trips during COVID-19 (1 if the respondent travelled for business at least once a month or more, 0 otherwise)		55.10%	44.90%
Business area (1 if skilled manual worker, 0 otherwise)		35.10%	64.90%
Level of agreement with the statement “I would be concerned about the effect HEART would have on the local area e.g., environment and economy” (1: strongly disagree—7: strongly agree)		63.26%	36.74%
Gender (1 if male, 0 otherwise)		82.59%	17.41%
Number of observations		882	
Log-likelihood at convergence		−631.21	
Restricted log-likelihood		−768.49	
McFadden pseudo-R^2		0.179	

Table A3. Bivariate ordered probit model of frequency to use.

Variable	Business Trips			Leisure Trips		
	Parameter	*t*-Stat	*p*-Value	Parameter	*t*-Stat	*p*-Value
Constant	−1.426	5.26	0.00	−1.633	7.57	0
Gender (1 if male, 0 otherwise)	0.157	1.70	0.09	0.169	2.09	0.0367
Age (18–29; 30–44; 45–60; older than 60)	−0.297	−7.09	0.00	−0.149	−4.01	0.0001
Annual household income (less than GBP 15,599; 15,600 to 25,999; 26,000 to 36,399; 36,400 to 51,999; 52,000 or more)	0.081	2.57	0.01	-	-	-
High annual household income (1 if greater than GBP 36,400, 0 otherwise)	-	-	-	0.182	2.46	0.0138
Area of residence (1 if urban, 0 otherwise)	0.170	2.30	0.02	-	-	-
Requiring assistance in everyday life (1: not at all affected—7: extremely affected)	0.064	2.26	0.02	-	-	-
Personality trait (1 if openness, 0 otherwise)				0.153	1.74	0.081
Train use for business trips (1 if respondent uses train mainly for business trips, 0 otherwise)	0.372	3.95	0.00	-	-	-
Car use for business trips (1 if respondent uses car mainly for business trips, 0 otherwise)	0.318	3.95	0.00	-	-	-
Car use for leisure trips (1 if respondent uses car mainly for leisure trips, 0 otherwise)	-	-	-	0.212	−2.94	0.0033
Business trips reduction due COVID-19 (1 if frequency of business trips during COVID is lower than before COVID, 0 otherwise)	0.406	4.80	0.00	-	-	-
Reliability for business trips (1 if reliability is among the three lowest-ranking factors of importance for trip planning, 0 otherwise)	0.203	2.61	0.01	-	-	-

Table A3. *Cont.*

Variable	Business Trips			Leisure Trips		
	Parameter	*t*-Stat	*p*-Value	Parameter	*t*-Stat	*p*-Value
Safety/security for leisure trips (1 if safety/security is among the three highest-ranking factors of importance for trip planning, 0 otherwise)	-	-	-	0.158	2.38	0.0174
Connections for business trips (1 if the number of required connections is among the three highest-ranking factors of importance for trip planning, 0 otherwise)	0.256	2.97	0.00	-	-	-
Importance of carbon footprint when traveling by plane (1: not at all important—7: extremely important)	0.068	2.69	0.01	0.055	2.38	0.0172
Number of observations	966					
Log-likelihood at convergence	−1455.54					
Restricted log-likelihood	−1876.71					
McFadden pseudo-R^2	0.224					

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