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Strategy for 19- seat hybrid-electric short haul air transportation

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Abstract. This paper addresses a way to implement greener aviation technologies, such as hybrid-electric propulsion, into the air transportation network to respond to the increasing environmental challenges posed by growing air traffic. New routes could be established between small airports to ensure better air connectivity in Europe while also connecting disadvantaged areas and relieve congestion at hub airports. Such routes could, for example, be served by micro feeder or 19-seat hybrid-electric aircraft, which produce low or no emissions, have lower operating costs, and are more applicable to environmental constraints. To achieve this and overcome the various challenges posed by the new hybrid-electric technologies, a new strategic roadmap for short-haul air transport is needed to optimize network services with small hybrid-electric aircraft.

1. Introduction

As part of the European Green Deal, the recent "Fit for 55" plan has raised new climate targets and committed to reducing greenhouse emissions by at least 55% by 2030 from before 40% [1]. Europe is as determined as ever before to achieve climate neutrality by 2050. The recent high and unexpected increase in EU emission allowance prices has shown that industry also realizes that climate targets are not just on a paper written political propaganda. As already highlighted by the European Vision for Aviation – Flightpath 2050 – environmental protection will continue to be a prime driver in developing aircraft and new transport infrastructure in the future. The aim is to reduce CO_2 emissions per passenger kilometre by 75% and NO_x emissions by 90% by 2050. In addition to climate targets, Flightpath aims that by 2050 passengers will be able to travel door-to-door in just 4 hours. This cannot be achieved without significant investments in infrastructure, high-speed transport systems, multimodal flight planning, information, online reservation systems, smart ticketing, etc. The micro feeder and regional aircraft market offer an excellent opportunity for 4-hour door-to-door services. These services could use environmentally friendly aircraft, such as hybrid electric models. The European Commission emphasizes that to ensure better connectivity within the EU, various options should be considered, offering destinations at small and smaller regional airports to avoid disadvantages for less-connected cities, regions, or countries [4]. Therefore, a new strategic roadmap for the aviation industry is needed to optimize network services. Services using small hybrid-electric aircraft operating at small regional airports could be one of the viable ways forward. This strategy focuses on two new innovative hybrid-electric aircraft technologies, the ICE-hybrid and fuel cell hydrogen propulsion systems for 19- seat turboprop passenger aircraft. While the ICE-hybrid does so partially, the fuel-cell eliminates CO_2 and NO_X emissions, which are currently a major challenge for European Commission's endeavours in achieving climate neutrality.

1.1. Raising concerns about aviation's environmental impact
Almost all forms of air transport release carbon dioxide (CO_2) and other greenhouse gases into the earth's atmosphere, contributing to the acceleration of global warming and also the acidification of the oceans [5]. Before to the COVID-19 pandemic, aviation accounted for 13.9% of transport emissions, making it the second-largest source of transport-related GHG emissions after road transport [6].

In Europe, passenger and cargo flights resulted in 189 and 192 million tonnes of CO_2 emissions in 2018 and 2019, caused mainly by passenger flights [7]. While the primary greenhouse gas emission from powered aircraft in flight is CO_2, other emissions may include nitric oxide and nitrogen dioxide (together termed oxides of nitrogen or NO_x), water vapor, and particulates (soot and sulphate particles), sulphur oxides, carbon monoxide (which bonds with oxygen to become CO_2 immediately upon release), incompletely burned hydrocarbons, tetraethyllead (piston aircraft only), and radicals such as hydroxyl, depending on the type of aircraft in use. For Europe (e.g., all flights departing from EU28 and EFTA airports), the flight emissions assessment based on IMACT models show that if aircraft technology remains unchanged from 2005 to 2040, CO_2 emissions are expected to increase by almost 60%, NO_X for 103% and volatile PM from for 61% [8]. By 2050, CO_2 emissions in Europe are expected to increase by 1.6% per year, resulting in 67% more emissions than 2018 levels. This would result in around 115 million tonnes of emissions for flights within the EU and flights outside Europe 178 million tonnes of CO_2. So, to achieve net-zero growth, at least 293 million tonnes of CO_2 would need to be eliminated [7].

Comprehensive research shows that despite anticipated efficiency innovations in airframes, engines, aerodynamics, and flight operations, the CO_2 emissions are expected to grow [9], [10], due to the projected continued growth in air traffic [11], [12]. According to ICAO, global aviation emissions are projected to increase by 322% between 2006 and 2050 under optimistic assumptions for technology and operational improvements, and 347% under moderate assumptions for improvements [13]. International aviation emissions could triple by 2050 if aviation continues to use existing aircraft technologies [6].

1.2. Approaches to mitigating aviation emission
Various pathways and scenarios have been outlined by Destination 2050, Waypoint 2050, and IATA Aircraft Technology Roadmap by 2050 to minimize the environmental impact of aviation in the coming years. Measures to reduce CO_2 emissions vary. While the Waypoint develops several possible scenarios and concludes that SAF will make the largest contribution to reducing carbon emissions, Destination 2050 states that by 2050 improvements in technology, including hydrogen-powered aircraft, will make the largest contribution to reducing emissions, followed by SAF and kerosene-powered or (hybrid) electric aircraft and other measures. In considering revolutionary propulsion technologies, the IATA Roadmap includes all-electric systems based on batteries and hybrid-electric propulsion. However, hydrogen as an energy source was not considered in the simulation.

Nevertheless, the roadmap acknowledges that hydrogen fuel cells could have advantages over heavyweight batteries but emphasizes that this would require a sufficient hydrogen supply system to be realized in commercial aviation. Although the roadmap differs in approach to how potential emissions should be assessed, it outlines a very important timeframe for entry into evolutionary and revolutionary technologies, such as hybrid-electric aircraft, consistent with the Waypoint 2050 and Destination 2050. All three above approaches show that emission reductions cannot be achieved by a single measure alone and that various actions, such as operational and infrastructure improvements, financial measures, and evolutionary technologies in aircraft and configurations are most likely to reduce emissions in the short term, while revolutionary technologies are needed to reduce emission in the long term.

In the long term, radical improvements, and technologies such as hydrogen aircraft will predominate in efforts to reduce carbon emissions. To reduce aviation emissions, all stakeholders must

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work together: governments, aircraft and engine manufacturers, airlines, airports, air navigation service providers, and the energy sector [7], [14], [15].

Introducing a new propulsion technology in the small aircraft segment seems to be a way forward, as it allows upscaling with lower development costs and business risks. As concern for lowering aviation emissions remains, a step forward to minimizing the negative environmental impacts of conventional aviation is introducing new, greener aircraft propulsion technologies, such as ICE – hybrid and fuel-cell aircraft.

1.3. ICE-hybrid and fuel cell hydrogen aircraft

Two types of hybrid electric aircraft are considered in the strategy. One is the ICE-hybrid aircraft, where the energy source consists of batteries and a classical internal combustion engine powered by kerosene. The other is the fuel cell hydrogen aircraft, which uses fuel cells powered by hydrogen.

An ICE-hybrid can minimize emissions during take-off and landing by running solely on electricity, while the cruise flight is performed using ICE. Such an aircraft can eliminate local toxic gases and significantly reducing noise emissions. However, it would contribute less to reducing of CO_2 emissions because it would continue to burn jet fuel in cruise mode. We can distinguish between parallel and serial ICE-hybrid aircraft. While in a parallel ICE-hybrid aircraft the propulsion is provided by an internal combustion engine (powered by kerosene) or by an electric motor (powered by batteries), in a serial ICE-hybrid aircraft, the propulsion is provided only by the electric motor, which can be powered either by a generator or by batteries.

A fuel cell hydrogen aircraft is one in which the electric motor is powered by a fuel cell system that uses hydrogen as the primary energy source. In contrast, batteries can be used as an additional energy source during take-off and climb. The fuel cell can convert hydrogen energy directly into electrical energy. Fuel cell aircraft emit no CO_2 or NO_X emissions, only water vapour. The most common fuel cells used in aviation are Proton Exchange Membrane Fuel Cells (PEMFC). The use of fuel cells as part of the propulsion system is currently limited to small, short-range aircraft. Therefore, for the time being, most potential applications of fuel cell technology will be found in piston and turboprop aircraft.

Hybrid-electric technology currently dominates in small seat segment, with the majority of current business applications expected in aircraft up to 10 seats, while also some research endeavours exist for developing a hybrid-electric 19-seater, such as by company Ampaire [17], Dante Aeronautical, and ZeroAvia with 19-seat hydrogen-powered electric aircraft based on a Dornier 228 platform.

2. Challenges of hybrid-electric short haul air transportation

The most critical factors impacting the implementation of hybrid-electric aircraft are the state of the technology, system integration, funding, certification, infrastructure at airports, social acceptance, hydrogen production, manufacturing costs, and policy support.

The biggest challenges will be **scaling the technology** to larger aircraft that have higher energy requirements, need higher-voltage power, and have more powerful fuel cells [18]. On the other hand, there are considerations of lowering weight by lighter components, especially hydrogen tanks. **System integration** will be a major challenge that would need to be addressed, preferably with an **open research approach, collaboration,** and **funding**. To ensure the market entry of hybrid electric aircraft, their technology readiness level should be achieved through a research program, at least 5 years before planned entry on the market [19].

New aircraft technologies and infrastructure at airports will also require authorities to adopt **new standards and guidelines**. The use of new sustainable fuels at airports is currently very strictly regulated and only allowed on a case-by-case basis and not for general commercial operations. Thus, many efforts must be made to establish the regulatory framework for hydrogen use, storage and distribution, and to license airlines on how to use it. In the longer term, the certification process will be a major challenge in terms of time. Certification should be supported by governments and specific programs [20].

On the side of **infrastructure** for ICE-hybrid aircraft, there are fewer challenges as for hydrogen aircraft. The biggest bottleneck for the near-term adoption of hydrogen aircraft will be on the airport side, specifically the lack of hydrogen ground infrastructure at airports, including production, distribution and refuelling, and also storage, as there are few companies so far that can offer a certifiable solution in this regard [21]. The positive aspect is that the ground mobility sector is adopting hydrogen with initiatives towards hydrogen hubs. These hubs, located close to airports, could also power aviation and allow airports to transition more quickly [19].

Also, **people's attitudes towards new types of aircraft**, which will be powered by new energy sources and differ in design from today's aircraft, will play a crucial role in market acceptance. People need to be comfortable traveling with hybrid, especially hydrogen aircraft, and be aware that they contribute to reducing climate impacts [18].

The **production** of green hydrogen has to become cheaper. It is also necessary to define a **clear vision for the use of hydrogen as aviation fuel** so that the European energy system can provide sufficient quantities and forms of hydrogen for all users, besides aviation, including existing users in industry and other transport [20].

After the technology has matured and certification has been completed, the main challenge will be to ensure that airlines adopt it at a scale that can mitigate aviation's climate impact[22]. Any investment in a new aircraft and especially in new propulsion technologies such as hybrid is risky. No manufacturer will be willing to take such a risk if no airlines express their commitments for purchases. On the other hand, airlines will not be ready to buy an aircraft that does not have appropriate seat capacity, range, price and operating costs. The positive side here is that although at the beginning the new hybrid-electric aircraft are expected to have higher purchase prices than existing models, in time they will become affordable as technology progresses. At the same time, they will allow airlines to lower operating costs due to lower costs for fuel [23]. A survey of airlines shows that airlines in the category of up to 50 seats would be willing to pay 5-10% higher prices for aircraft if they could save 10-20% on operating costs [24].

To scale technology currently being tested to up to 4-seat aircraft solely by industry efforts will be too time-consuming and jeopardize EU climate goals. Therefore, the government’s initiatives or market mechanisms will play a crucial role [22]. The technology development will need to be accelerated to achieve desirable environmental goals in aviation on time [25]. **Policy support** will accordingly be required, not only to provide a clear aviation and energy roadmap for Europe and regulatory frameworks, but also sufficient funding for research and innovation, necessary investments for airport infrastructure, funding aircraft development and production, and incentives for airlines to purchase such aircraft.

Therefore, the introduction of ICE-hybrid aircraft and fuel cell hydrogen aircraft will be affected by many challenges, however it is also expected to introduce several opportunities.

3. Market opportunities for short haul transportation

The regional aircraft market comprises a distinct submarket within the airline market, covering short-haul flights, accounting for 54% of total revenue passenger kilometres (RPKs) in 2020. The regional market for turboprops and jets offering domestic flights to major hubs is expected to remain an important infrastructure for global connectivity and have increasing relevance as COVID-19 recovery is led by domestic traffic. Regional aircraft are expected to be used for routes not currently served by short-haul turboprops and long-haul single-aisle jets, and turboprops are expected to be used for smaller niche markets in Europe and in particular for cases with short runways and under challenging environments (e.g., mountains, islands) [26].

As non-European manufacturers currently lead the European regional market, there is also a strong tendency to gain a competitive advantage. Several new aircraft technologies that are more efficient and environmentally friendly are expected to be introduced in the regional market in the coming years [27]. The main driver of the turboprop market in Europe was the recent development of new small and medium-sized airports, modernization of the existing fleet, acquisition of new turboprop aircraft, and new shorter routes. Operating European routes with turboprop aircraft would have benefits in fuel efficiency, costs, and emissions [28].

The segment of 19-seater turboprop aircraft includes several aircraft models, such as Dornier 228, DHC-6 Twin Otter (Viking -400), Beechcraft 1900, Fairchild Dornier Merlin /Metro 23, Let L-410, Jetstream 31/32 [29], [30], [31]. While most of them are still in use, several of them are already out of production, leading to airlines having aging fleets of turboprop needed to be replaced in the next decade [24]. As the largest European manufacturer in the regional aircraft market, some manufacturers like ATR are already considering to manufacturing 19-seat aircraft soon [28].

The majority of air services that are offered by 19-seat aircraft are within 80 and 800 km range, with most flights being under 400 km [32]. Flights with 19-seaters occur mainly in the northern part of Europe, mostly connecting the mainland and inland in the United Kingdom, Scotland, and Irish Sea, and connecting Italian islands with the mainland. Some flights are also carried within countries such as Norway, Sweden, Iceland, or even between countries (such as Norway and Denmark). In most cases, air travel, especially in the case of inlands and poor or no railway connections (e.g. Iceland), reduce travel time three-fold compared to car and five-fold compared to rail [31].

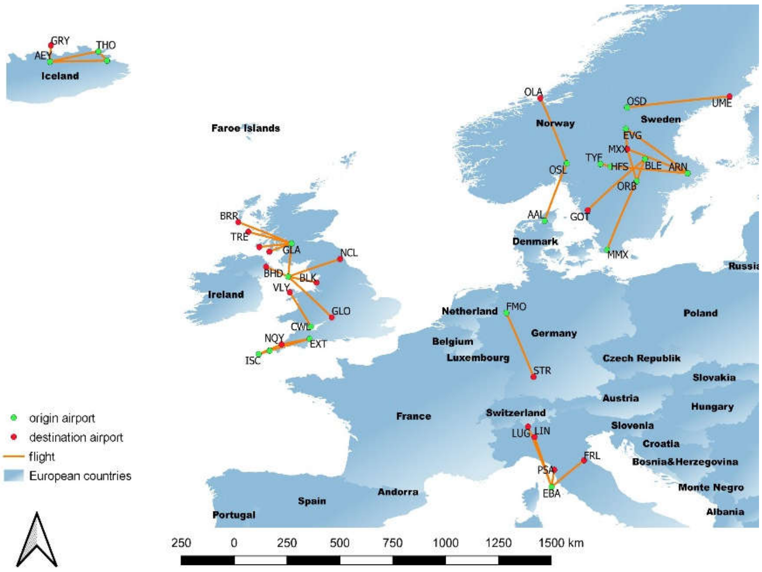

Figure 1: Flights operated by 19-seater in Europe

The opportunities of 19-seat hybrid-electric aircraft lie in their novelty, low or zero emissions, lower operating costs, and better applicability in terms of environmental restrictions. Because of the quiet, short take-off and landing capabilities with zero or low gas emissions, ICE -hybrid and fuel cell hybrid hydrogen aircraft can be used at today's **underutilized airports** in urban areas, near city centres. The 19-seat ICE-hybrid and fuel-cell hydrogen aircraft are expected due to possibility of using all electric take off to be much quieter than current conventional aircraft, giving them advantages at **airports with noise-related operating restrictions**. The 19-seat fuel-cell hydrogen aircraft will have competitive advantages over traditional aircraft at airports that impose **penalties for NO_X emissions**, such as some airports in Switzerland, Sweden, England, Germany, and Denmark. Hybrid-electric aircraft could be used at **secondary airports** to avoid connections to hub airports with severe problems due to congestion that also cause major delays. This could beneficially contribute to Flight Path's goal of "enabling door-to-door travel within 4 hours in Europe." While there are 69 hubs with more than 5 million passengers per year, 1,908 secondary airports and 1,101 airfields already have sufficiently long runways and could be used for hybrid-electric, short-haul air travel with little or no additional airport infrastructure. While there are some considerations that large investments will be required at airports to ensure sufficient hydrogen supply, this is true in the case of large airports and large quantities of hydrogen. For smaller airports operating short-haul flights, liquid hydrogen could be distributed by trucks, which has less of an impact on airport infrastructure than on-site production [33]. As hybrid-electric aircraft can make the round trip without recharging or refuel at each airport, this would also offer a significant advantage, as not all airports would need to be equipped with charging infrastructure [34].

Hybrid-electric short-haul air services could be used in regions **with no high-speed railway** system. They could be used instead of conventional aircraft and lower or eliminate emissions. Switching to (high-speed) rail is not an option in all parts of Europe. Where such networks do not yet exist, this would require significant investment and time to build rail lines even up to 20 years. This cost is borne by Europe's citizens and causes CO_2 emissions during construction or maintenance. At the same time, noise generated by rail affects 5 times more European citizens than aircraft noise (so 21.9 million vs. 4.2 million) [15].

Additionally, they could be used in regions where **limits are imposed on short flights**. Such a case occurred in Austria, where financial support for Austrian airlines was given under the condition that they impose a €30 surcharge on flights of less than 350 km and limit all flights to destinations that can be reached by train within 3 hours. The argument behind such measures is to reduce emissions from aviation by reducing the number of flights. The same could be achieved by providing flights with hybrid-electric aircraft while avoiding an unnecessary reduction in air connectivity [35]. Small hybrid-electric aircraft would offer more suitable regional aircraft in terms of range and capacity and reduce the use of oversized aircraft on short-haul routes, with lower emissions and operating costs than conventional small aircraft.

The opportunities offered by hybrid-electric aircraft also concern **costs**. **Jet fuel prices** have been steadily increasing (except during the current COVID-19 pandemic), and this increasing trend is expected to continue after the recovery. On the other hand, green hydrogen and electricity prices are expected to fall due to the massive deployment of renewable sources. The **price of hydrogen** will break even around the year 2030 and become a cheaper option than jet fuel or synfuel [36]. Green hydrogen production will cost around €3/kg by 2030 and could fall below €2/kg by 2050 [37]. This will make flying with hydrogen and electricity cheaper than with kerosene or synfuel. The prices of crucial components of hybrid-electric aircraft such as batteries, fuel cells, and hydrogen tanks are expected to fall due to technological development. The average price of **lithium-ion batteries** is now 8 times cheaper than ten years ago and is expected to fall to between €60/kWh and €80/ kWh in the following years [38]. The price of **Proton Exchange Membrane Fuel Cell** is already three times lower today than in 2006. The price will fall to €25/ kWh by 2030 and to €17/ kWh by 2050. [39]. This means that also production cost of hybrid-electric aircraft will significantly fall. In addition to lowering the manufacturing cost of hybrid-electric aircraft, entry for newcomers will become possible, which is currently very difficult due to a highly competitive market and strict safety and reliability requirements, as well as the high cost of certification. The development of new radical technologies that require different design methods and certification procedures may present an opportunity for new companies to enter the market and create niches [40].

4. Conclusions

Small aircraft, such as 19-seaters, are most likely to be the first to adopt new hybrid-electric propulsion technologies and take advantage offered by cleaner aviation. Due to the COVID-19 pandemic, more and more business is being conducted online, and traveling has decreased. This has led to the current use of oversized aircraft on certain routes. Therefore, such events could accelerate the adoption of smaller hybrid-electric aircraft. The 19-seat hybrid-electric aircraft could be used either for new air services and routes or to replace existing ones and contribute to lower emissions and operating costs. Using hybrid-electric aircraft could bring several benefits in terms of reduced travel times, improved air connectivity, and shifting traffic from the ground, while also having a significant economic impact on the local economy by using local airports and small aircraft manufacturers. Hybrid-electric aircraft could be used for a variety of purposes, such as commercial regional flights with point-to-point connections between smaller airports to minimize the pressure caused by hub congestion; charter flights to tourist destinations, especially to remote islands or other remote areas (i.e. as bush planes); private flights or coach flights, with emphasis on short travel times and comfort; air taxi flights connecting urban areas and other flights, such as training, surveillance, medical, and panoramic flights, etc. The most likely market where new technologies such as hybrid-electric propulsion will be used is commuter services providing connections, where road travel would be too time-consuming or rail services too expensive. Revolutionary new aircraft designs should lead to a change in air travel. Instead of going through overcrowded hubs in Europe to reach some part of Europe, this could be done by directly connecting small and medium airports. The new way of traveling will be adopted much faster if an appropriate airport ground infrastructure is available. The path to short-haul transportation with new and innovative hybrid-electric aircraft is accompanied by many challenges, from the technological perspective of changing the technological paradigm to the economic uncertainties of future prices of existing and new aviation fuels, to the costs of "making it fly" and the ability of policymakers to identify and adequately assess which path will is the best in terms of resources and minimizing environmental impacts.

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