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MARKET PROSPECTS FOR A HYBRID TURBO-ELECTRIC PROPULSION (HTEP) WITH FUEL CELLS FOR A REGIONAL AIRCRAFT WITH 80 SEATS

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Summary. *Traditional commercial airplanes fall into three categories: single-aisle (narrow-body), twin-aisle (wide-body), and regional aircraft, the smallest type. This classification provides a key understanding of aircraft dimensions and capacities, crucial for integrating hybrid technologies and fuel cells. Hybrid aircraft, anticipated as the future of regional aviation, may replace turboprop models but not necessarily conventional jets.*

Despite pandemic impacts, global air travel is projected to recover by 2024, driven by pandemic recovery, geopolitics, and industry shifts. Forecasts suggest a 3.2% annual growth in global revenue passenger kilometers (RPK) until 2042. The translation of this growth into the regional market will influence the success of innovative hybrid aviation technologies.

The EFACA Project (Environmentally Friendly Aviation for All Classes of Aircraft), funded by the European Union (UE) from 2023-2026, is developing a hybrid turbine-electric propeller (HTEP) system with fuel cells for regional aircraft (up to 80 seats, 1000 km range). The project defines top-level HTEP requirements systematically, assesses power supply concepts, and advances component designs, fuel supply, storage, conditioning, and power systems.

This paper explores the potential market for the HTEP design, analysing affected markets, including hybrid and fuel cell aircraft and regional aviation, with a focus on driving forces. It also scrutinises market shares in regional and short-haul routes, refining top-level aircraft requirements. The discussion covers technological attributes, prospects for various aircraft markets, and pre- and post-pandemic market shares, concluding with final remarks.

1 INTRODUCTION

The classification of conventional passenger aircraft into three main categories -single-aisle (narrow-body), twin-aisle (wide-body), and regional aircraft, regional aircraft, being the smallest type - provides a framework for understanding their size and capacity. Regional carriers typically operate aircraft with seating capacities ranging from 19 to 130 seats, on short

to medium-haul routes. These can be further subdivided into regional jets and turboprops, the latter using propellers driven by a turboprop engine and the former using jet engines for thrust [1].

The distinction between regional jets and turboprops in regional aircraft lies in the type of engine propulsion they use. Turboprop engines use the energy released from combustion to rotate a propeller, which, in turn, generates thrust to propel the aircraft forward. In contrast, jet engines use combustion energy to accelerate exhaust gases backward, producing the thrust necessary for forward motion. The differing mechanisms result in variations in performance. While turboprop engines typically provide less thrust than jet engines, they are known for their fuel efficiency. This characteristic makes turboprop aircraft well-suited for shorter ranges. They tend to operate at lower altitudes and lower speeds than regional jets.

This framework is also relevant for the introduction of the paradigm of hybrid technologies and fuel cells in aviation. All-electric and hybrid aircraft, propelled by a propeller, exhibit flight performances similar to turboprop aircraft. As a result, it is expected that hybrid aircraft could replace turboprop aircraft but may not necessarily replace jet aircraft.

Before the COVID-19 pandemic, regional aviation experienced robust growth, accounting for over 12% of world available seat kilometres (ASK) [1]. The aftermath of the pandemic has impacted global economic development and air travel, leading to a gradual recovery. World passenger traffic, measured in revenue passenger kilometres (RPK), is expected to return to 2019 levels by 2024, driven by factors such as pandemic recovery, geopolitical considerations, and industry dynamics [2]. Global RPKs are projected to grow at an annual rate of 3.2% through 2042 [3]. How this overall growth will be translated into the regional market and how the particular driving forces affecting the regional market will evolve, will highly influence the prospects for new hybrid technologies in aviation.

With these perspectives in mind, EFACA Project (Environmentally Friendly Aviation tor All Classes of Aircraft) supported by the European Union in the period 2023-2026 is developing the concept of a hybrid turbine-electric propeller (HTEP) aircraft system with fuel cells for a regional aircraft with a capacity of up to 80 seats and a range of up to 1000 km.

In particular, the EFACA project takes a sequential approach to defining the HTEP design, starting with the initial definition of top-level requirements for both the HTEP and the aircraft. The process then involves evaluating conceptual schemes for the HTEP power supply, followed by the preliminary formation of HTEP component designs and subsequently, the development in fuel supply, storage, fuel conditioning, and power distribution and management systems.

Based upon the consideration of the top-level requirements for the HTEP, this paper addresses the potential market of this design. This paper includes a detailed analysis of the prospects for the different markets affected, that is hybrid aircraft, fuel cell aircraft and the regional aircraft market, including its major driving forces to determine what will be the potential market for the hybrid-electric fuel cell aircraft. The results of the analysis will be an interesting input to tune top level aircraft requirements, in particular, the design flight range.

The rest of the paper is organised as follows. Section 2 discusses the technological characteristics of the regional fuel cell and hybrid-electric aircraft. Section 3 discusses the prospects for the three aircraft markets concerned, with the aim of identifying the most feasible segments for this hybrid aircraft. Finally, Section 4 presents the main conclusions of the study and lists a series of further research avenues based on the results of the present analysis.

2 TECHNOLOGICAL CHARACTERISTICS OF REGIONAL FUEL CELL AND HYBRID-ELECTRIC AIRCRAFT

While land transport electrification has progressed, replicating this in aviation faces challenges due to the low specific energy of batteries. All-electric aircraft would be heavier, larger, and have shorter ranges. A more electric propulsion system and the potential impact of increased battery energy are explored. According to [4], given the limited specific energy of batteries (0.1–0.25 kWh/kg) compared to kerosene's energy density (12 kWh/kg, or 4 kWh/kg with combustion engine efficiency considered), and the unlikely significant improvement in battery energy in the near future, the regional aircraft market is expected to rely on hybrid configurations.

Hydrogen, with higher energy density and future fuel potential, powers fuel cells for electric current, driving an emission-free, low-noise solution. Fuel-cell technology is under development, but commercial hydrogen fuel-cell passenger aircraft may not be imminent due to technical challenges.

Hybrid aircraft, with parallel or serial propulsion systems, emerge as a feasible medium-term solution. In contrast to batteries, hydrogen presents a higher energy density than kerosene, positioning it as a prominent future fuel due to the limitations of fossil fuels. Aircraft using hydrogen in fuel cells generate an electric current, powering an electric motor connected to a propeller [5]. Despite ongoing fuel-cell technology development, commercial hydrogen fuel-cell passenger aircraft are not anticipated in the immediate future. Challenges arise from the high mass of hydrogen tanks, presenting a drawback for small passenger aircraft.

A hybrid hydrogen fuel-cell aircraft, as the concept developed by EFACA project, could be the key to bridle for the sustainable future of the regional market. EFACA is developing the concept of a hybrid turbine-electric propeller (HTEP) aircraft system with fuel cells for the regional market with a capacity of up to 80 seats and a range of up to 1000 km.

3 PROSPECTS FOR THE RELEVANT MARKETS

To better understand the possible market for the EFACA regional aircraft concept, this section analyses the current status and prospect of several relevant aviation markets. Three main markets are addressed. The first two, hybrid and fuel cell aircraft markets are emergent markets affected by high uncertainties but offering big development opportunities. The last one, the regional aircraft market, including both turboprops and regional jet aircraft, is a well-established market although affected, however, by important changing forces. This regional market will be interrelated in the future with the first two ones.

3.1 Hybrid market analysis

The current hybrid aircraft market integrates both electric and conventional fuel-based propulsion systems, aiming to minimise emissions and fuel consumption. The market is segmented based on aircraft type, mode of operation, lift technology, power source and region [6]. Aircraft types include regional transport aircraft, business jets and light aircraft, UAVs, and Advanced Air Mobility (AAM). Modes of operation are categorised as piloted and autonomous, while lift technologies encompass conventional take-off and landing, short take-off and landing, and vertical take-off and landing. Based on power source, the hybrid electric aircraft market has been segmented into fuel hybrid and hydrogen hybrid.

The growth of the hybrid aircraft market is propelled by factors such as increasing demand for short-haul range connectivity, technological convergence, increasing demand for alternate modes of transportation, enhanced fuel efficiency compared to conventional aircraft, progress in electric propulsion technology, and increased investments from industry stakeholders.

However, the hybrid aircraft market faces significant challenges due to the high development costs associated with researching, designing, and producing hybrid propulsion systems. Expanding beyond prototype development would necessitate substantial investments. The lack of dedicated airport infrastructure poses also a significant challenge for the adoption of novel Vertical Take-off and Landing (VTOL) hybrid aircraft designs, especially those targeted for urban air mobility. Despite these challenges, new applications in urban air mobility and a rising adoption of hybrid aircraft for defence purposes present significant growth opportunities for market players.

Estimations on the market size and its prospects vary by a factor of 10 depending on the source consulted. According to Allied Market Research [7], the global hybrid aircraft market size is expected to be valued at $1.9 billion in 2025, and is projected to reach $10.2 billion by 2035, growing at a CAGR of 18.2% from 2025 to 2035. The results presented in [7] estimate hybrid aircraft market growth from USD 1.2 billion in 2023 to USD 13.2 billion by 2030, at a CAGR of 41.6%. This market is approximately one-tenth of the commercial aircraft market in 2032 estimated in $344 billons at a CAGR of 4%, and just one- twentieth of the smart fleet management market which is estimated be of $600 billion by 2030 at a CAGR of 9%.

North America leads in global hybrid aircraft progress. Regarding countries, the U.S. takes the lead. Europe is anticipated to show the highest growth and market share in the hybrid-electric aircraft market due to technological progress, increased demand for efficient transportation, and supportive government initiatives fostering market development. Asia-Pacific, with unique strengths in drone manufacturing, battery technology, and software talent, is driving niche advancements in hybrid aircraft. The region's high urban congestion supports the growth of hybrid electric vertical takeoff and landing (eVTOL) air taxis.

3.2 Fuel cell aircraft market

Aircraft powered using fuel cells play a role in the aviation industry, serving as an efficient and clean power source for various applications. These fuel cells operate by converting the chemical energy of fuels such as hydrogen or hydrocarbons into electricity through an electrochemical process. In the aircraft fuel cell industry, these cells are employed in propulsion systems, contributing to the development of more efficient and environmentally friendly aircraft engines. Additionally, they find applications as auxiliary power units (APUs), providing electricity for aircraft systems during ground operations and reducing reliance on traditional engine-based power generation. Furthermore, fuel cells are used as back-up power sources in emergency situations, ensuring the uninterrupted operation of critical systems. By powering essential equipment and systems, such as communication, navigation, and safety devices, fuel cells enhance aircraft safety and reliability.

To understand whether fuel cell propulsion is a viable option for aircraft, it is necessary to consider the impact of the fuel cell system on the aircraft. Key parameters include the impact on weight, volume and performance [8]. Today applications of fuel cell in aviation are far away from becoming the main source of power of the aircraft, but there is however and important

market that constitute the first step for such future developments.

According to the results presented in [7], the fuel-cell aircraft market size is projected to grow from USD 1.6 billion in 2023 to USD 5.7 billion by 2035, at a CAGR of 10.8% from 2023 to 2035. The market is divided according to fuel type (hydrogen, hydrocarbon and others), power output (0-100kW, 100kW-1MW, 1 MW & above) aircraft type (fixed-wing, rotary wing, UAVs, AAMs) and region. The UAV segment accounts for the largest market size during the forecast period. The 0-100KW segment is projected to have a greater market share during the forecast period. Finally, Asia-Pacific is projected to hold the biggest market share during the forecast period.

The aircraft fuel cell market offers several prospects for expansion to players. Market expansion is being driven by innovation in fuel cell technologies, and the advent of new aircraft programmes and systems to power the future of smaller aircraft and electric flights. Main factors, according to [7], determining aircraft fuel cell market dynamics include:

- **Innovations in fuel cell technology and increased cost efficiency.** Fuel cell technology innovations act as a catalyst for market growth, driving progress in the industry. The critical factor influencing the adoption of fuel cell technology in aircraft is cost efficiency.
- The mayor restraint are the **problems associated with hydrogen storage and cooling**. Safe, technical and logistical issues need to be overcome to enable efficient and practical hydrogen implementation.
- **Innovations in High-Performance Proton Exchange Membrane** (HPTEM) technology offer the potential for improved fuel cell performance in aircraft. HPTEMs promise higher proton conductivity, leading to enhanced power output and energy efficiency.
- **Integrating efficient cooling systems for Low-Platinum Thin-Film Electrolyte Membrane (LPTEM)** fuel cells in aircraft is hindered by limited space and the need for lightweight solutions. LPTEM fuel cells generate heat, requiring careful thermal management to prevent overheating and ensure optimal performance.

3.3 Key trends and dynamics for the regional aircraft market

Despite global economic development, scheduled air traffic is still rebounding from the COVID-19 crisis. World passenger traffic is expected to return to 2019 levels by 2024 due to prolonged pandemic recovery, geopolitics, and industry changes. Flight operations are rapidly closing the gap, approaching within 5% of pre-pandemic levels, with some regions like Latin America, the Middle East, and Africa already surpassing them. Worldwide, all regions have achieved at least 90% recovery in flight activity, signalling a positive trend as the aviation industry steadily approaches or exceeds pre-crisis operational levels [9].

In the regional market, aircraft are categorised by seating capacity: 35 to 80 seats and 80 to 125 seats. Larger-capacity aircraft, from 80 to 125 seats, dominate global airspace and align with turbofan-equipped aircraft. Conversely, aircraft with seating between 35 and 80 predominantly feature turboprops and are primarily used for short-haul flights connecting rural and developing regions. Currently in production are only a select few aircraft within the 35 to 80 seating range, such as the DeHavilland Canada Dash8 Q400, ATR 72-600, ARJ21 and Ilyushin II-114-300. This market is declining as focus shifts to enhancing seating capacity.

Notably, these aircraft are increasingly used in cargo operations; FedEx, a major ATR72-600 F series customer, transports loads across small districts in America [10].

The regional jet market has faced challenges from a trend toward larger aircraft, causing financial strains on regional airlines. Key factors shaping the future of up-to-150 seat aircraft include:

1. **Fragmentation of Global Economy**: Regionalisation of businesses and supply chains favours airlines in this category, catering to changing demands of regional economies.
2. **Geopolitical Tensions:** Challenges in cross-border trade and disrupted global value chains drive a surge in global firms regionalising supply chains, impacting corporate strategies.
3. **Social Revolution and Remote Work**: Remote working alters travel patterns, creating air service opportunities in new communities.
4. **Market Effects of Sustainability:** Global sustainability push influences travel preferences. Demand for fuel-efficient aircraft and alternative fuels rises, but the transition may incur increased costs.
5. **Expansion of Middle-Income Households**: Projections indicate a surge in middle-class households.
6. **Regulatory and Competitive Environments:** The interplay of income levels, regulations, and competition shapes air travel growth, fostering innovation and accessibility.
7. **Airline Network Connectivity**: Up-to-150 seat aircraft play a vital role in serving regional routes, connecting smaller communities, and contributing to overall transportation infrastructure.
8. **Fleet Flexibility**: Adaptable fleets, including narrow-body aircraft, are essential for airlines to meet changing demand scenarios.

Balancing economic considerations, technological progress, and sustainability goals is crucial for meeting evolving airline industry demands and ensuring continued regional and global connectivity.

Main reginal aircraft manufacturers anticipate a global demand for 11000 new aircraft in the up-to-150-seat category over the next two decades, with an estimated market value reaching USD 650 billion [3]. The forecast indicates that 55% of these new deliveries will be allocated to replacing aging aircraft, addressing the need for fleet modernisation. Simultaneously, 45% of the new aircraft will be directed towards expanding and cultivating markets, reflecting a strategic approach to accommodate growth in air travel demand and emerging market opportunities.

The regional jet market can be analysed based on various regions, including North America, Europe, Asia Pacific, Latin America, and the Middle East and Africa. Each region exhibits unique characteristics in terms of market size, growth potential, regulatory environment, and demand patterns. Understanding regional dynamics is crucial for market players to identify opportunities and devise effective strategies to capture market share.

Table 1 presents figures related to the demand for new aircraft up-to-150 seats according to several aircraft manufacturers. As can be noted, figures slightly vary depending on the manufacturer.

Table 1: Demand for new aircraft up to 150 seats according to several aircraft manufacturers

Global prospects for the next 20 years			
	Regional market	Turboprops	Jets
	11000 units. USD 650 billion market value	2210 to 2450 units • 620 for the range 40-60 seats • 1830 for the range61-80 seats	8790 units
Prospects per region			
	Annual RPK regional growth rate – ranked	Turboprop deliveries – 2,210 (% share) – by region	Jet deliveries – 8,790 (% share) – by region
Asia Pacific (includes China)	44.4%	910 to 1255 units (41.0%)	2270 units (25.8%)
Latin America	4.1%	180 to 325 units (8.1%)	780 units (8.9%)
Africa	3.7%	210 to 230 units (9.5%)	320 units (3.6%)
Middle East	3.2%	50 units (2.7%)	340 units (3.9%)
North America	2.2%	240 to 410 units (18.5%)	2690 units (30.6%)
Europe/CISRPK	2.0%	400 to 450 units (20.2%)	2390 units (27.2%)

Production is still recovering from pandemic shutdown, with global manufacturers producing 152 regional aircraft in 2022, a 10% increase from 2021 This marks the first annual rise since the 138 aircraft manufactured in 2019.

When it comes into production the regional transport aircraft market analysis from Forecast International [11] anticipates significant activity in the sector from 2023 to 2032, with 2399 aircraft valued at $98.4 billion (2023 USD). Annual production is projected to increase to 162 aircraft in 2022, peaking at 293 in 2029. Anticipating a cyclical downturn, production is expected to dip to 251 units in 2030 and 249 in 2031, followed by a rebound to 275 units in 2032. Jet-powered aircraft are forecasted to constitute 54.9% of unit production and 78.4% of production value from 2023 to 2032, as graphically presented in **Figure 1**.

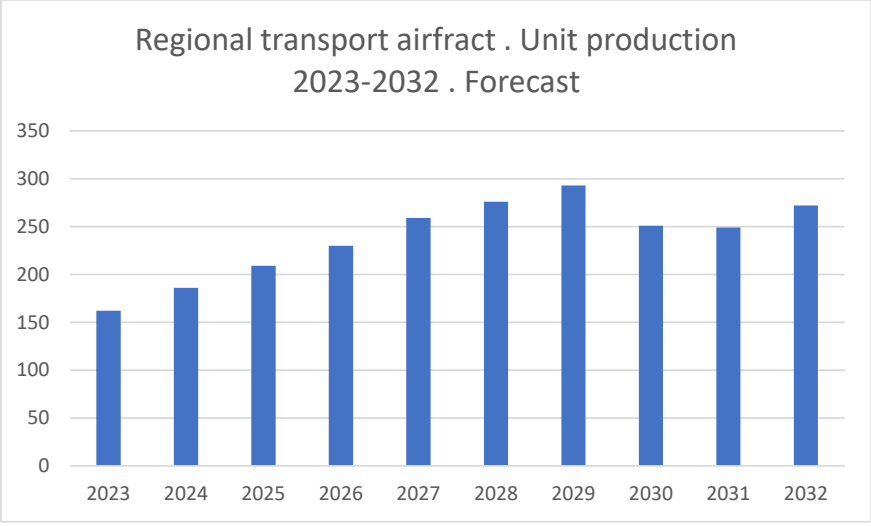

Figure 1: Forecast of regional transport aircraft unit production for the period 2023-2032 (Data from [11]).

Regarding production, the results from the regional transport aircraft market analysis from Forecast International [11] are listed below. Recent restructuring in regional aircraft manufacturing sees dominant players emerge. Bombardier and Mitsubishi exit, leaving Embraer as the top regional jet manufacturer, and ATR leading in turboprops. While Embraer's jet market dominance is stable, there is potential for competition in the turboprop market, with Embraer considering the launch of a new family of 70- to 90-passenger turboprop airliners in the early 2030s.

In terms of unit production, Embraer is projected to lead unit production with 754 regional jetliners (31.4% market share), followed by ATR with 661 aircraft (27.6% share). COMAC is third with 354 ARJ21 regional jets (14.8% share), and Cessna's SkyCourier turboprops rank fourth with 161 units (6.7% share). In terms of production value, Embraer leads with an estimated $49.4 billion (50.2% market share), followed by ATR at $17.6 billion (17.9% share). COMAC ranks third with $13.5 billion (13.8% share), and Airbus Canada's A220-100 holds the fourth position with $8.2 billion (8.3% share).

3.3.1 Commercial turboprop aircraft market

The commercial turboprop aircraft market is expected to witness new opportunities in the coming years, driven by the growing adoption of electric and hybrid propulsion systems in aircraft. This technological shift is anticipated to open up novel avenues for the market, signaling a transformative phase in the aviation industry.

The commercial turboprop aircraft market faces several specific challenges and risks that demand strategic navigation by manufacturers and stakeholders. Navigating these challenges requires a proactive and adaptive approach from manufacturers and stakeholders in the commercial turboprop aircraft market. Some of the turboprop aircraft market characteristics are listed below. The figures presented have been obtained from [12]. The key characteristics of the turboprop aircraft market are schematically presented in **Figure 2**.

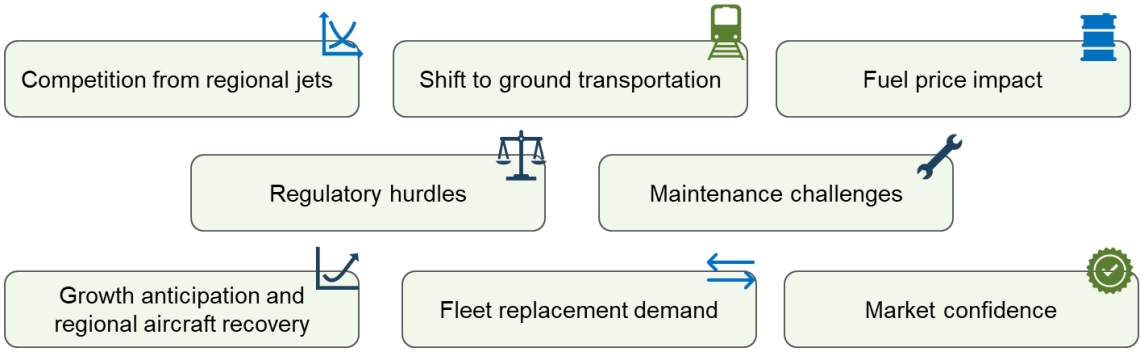

Figure 2: Commercial turboprop aircraft key characteristics.

- **Competition from Regional Jets**: Turboprop manufacturers must innovate for efficiency, cabin comfort, and economics to compete with faster, higher-capacity regional jets.
- **Shift to Ground Transportation**: Turboprops face reduced demand if efficient ground options replace short-haul routes. Manufacturers must emphasise turboprop relevance and cost-effectiveness in specific regions.
- **Fuel Price Impact**: Fluctuating fuel costs poses a risk to turboprop economics,

emphasising the need for manufacturers to highlight fuel efficiency advantages.

- **Regulatory Challenges**: Evolving emissions and noise regulations pose regulatory challenges. Compliance may require costly adjustments to aircraft designs.
- **Maintenance Challenges**: Skilled maintenance and spare parts availability pose challenges, especially in remote areas. Manufacturers need robust support networks for consistent performance and safety.
- **Growth Anticipation**: Anticipating 2450 new turboprops in the next 20 years signals recovery and potential expansion in the aviation industry.
- **Regional Aviation Recovery**: Regional aviation is near full recovery post-pandemic, with an average of 180 new routes annually in the past 10 years. 35% of the routes opened by turboprops still operate them when routes mature. Emerging markets like India, Brazil, and Indonesia are active in creating new routes.
- **Fleet Replacement Demand**: The aging turboprop fleet needs replacements. Projecting 1500 new aircraft for replacement in the next two decades indicates significant demand for newer, more efficient models.
- **Environmental Shift**: Turboprops offer an environmentally friendly choice, with lower CO_2 emissions than regional jets.
- **Disruptive Technologies**: Anticipation of disruptive technologies emerging from 2030 suggests turboprops will be at the forefront of shaping the aviation industry's future.
- **Market Confidence**: Confidence in turboprop market expansion beyond the forecasted 2450 aircraft reflects positive expectations, driven by technological advancements, changing regulations, and a preference for low-carbon aircraft.

Each region's unique characteristics contribute to the diverse demands and applications of commercial turboprop aircraft worldwide. ATR forecast [12] envisaged a demand for 2450 turboprops in the next 20 years, with new deliveries focussing on replacements of current aged fleet. With an in-service fleet of 1950 aircraft in 2022, by 2041 450 will stay in service, 1500 will be replace, 240 retired or converted and 710 new aircraft will correspond to the growth of the market.

3.3.2 Regional jets market

Regional jets, falling within the category of small to medium-sized commercial aircraft, are specifically designed to operate on short to medium-haul routes within a defined region or geographic area. Constituting approximately 6% of the commercial aircraft industry, these jets are employed by regional airlines that conduct flights on behalf of larger carriers, connecting smaller airports to major hubs. Characterised by their modest size, seating capacity, and range in comparison to larger airliners, regional jets typically accommodate between 15 and 125 passengers, with variations allowing for slightly more or fewer individuals.

The regional jet market has undergone consistent growth in recent years, propelled by the increasing demand for air travel and the need for efficient transportation solutions in regional areas. This upward trajectory reflects the crucial role that regional jets play in connecting smaller cities and towns, catering to the evolving travel needs of diverse communities. As a result, the market expands, driven by the pursuit of enhanced regional connectivity and the ongoing quest for streamlined and effective regional air transportation.

The outlook for the regional jet market is shaped by various factors, including the escalating demand for air travel, economic conditions, technological progress, regulatory policies, a growing need for regional connectivity, and a focus on fleet renewal and efficiency. This market is characterised by intense competition, with key players actively engaged in innovation to deliver efficient and cost-effective solutions that cater to the evolving requirements of regional airlines and passengers. Despite these drivers, challenges such as infrastructure limitations, airport constraints, and competition from larger aircraft and high-speed rail networks pose obstacles to market growth. However, opportunities for expansion emerge from the interest in extending air connectivity, establishing new routes, and augmenting existing ones.

The regional jet market plays a pivotal role in facilitating regional air transportation by offering efficient and convenient travel options for passengers within specific geographic regions. The increasing preference for air travel in regional and short-haul routes propels market growth. As more individuals opt for air transportation for regional journeys, the demand for efficient connectivity and convenient travel options within a given region continues to rise, thereby driving the increased adoption of regional jets. Airlines are actively engaging in fleet renewal and modernisation initiatives, aiming to enhance operational efficiency and decrease operating costs. The integration of advanced technologies, improved fuel efficiency, and heightened passenger comfort in newer models of regional jets is propelling the phase-out of older aircraft, contributing to a more contemporary and capable regional jet fleet. The regional jets market key drivers are graphically presented in **Figure 3**.

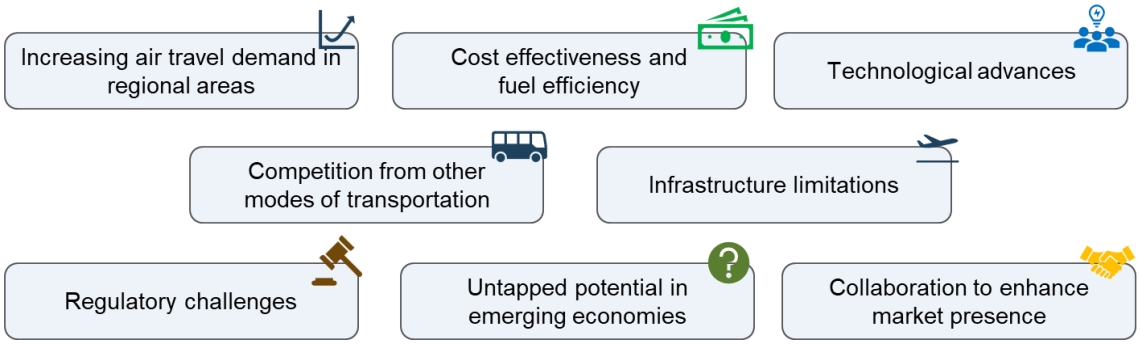

Figure 3: Regional jets market key drivers.

The regional jet market is categorised based on several factors, including platform, seating capacity, maximum take-off weight, and geographic region. Platforms encompass both commercial and military aircraft, while seating capacity is segmented into 15-80 seats and 80-125 seats. The market's geographical analysis spans North America, Europe, Asia-Pacific, and Latin America, Middle East & Africa (LAMEA), with detailed country-level assessments for each region. Some key figures related to the regional market according to Allied Market [13] are presented below.

- The global regional jet industry generated $5.7 billion in 2022, expected to reach $10.6 billion by 2032 with a CAGR of 6.4% from 2023 to 2032. The commercial aircraft segment dominates, accounting for over four-fifths of revenue. The military aircraft segment is projected to have the highest CAGR of 9.6%, meeting specific requirements.
- In terms of seating capacity, the 15-80 seats segment holds the highest market share, expected to maintain leadership. Meanwhile, the 80-125 seats segment is projected to have the highest CAGR of 8.3%, offering advanced avionics and modern amenities.

- Regionally, North America dominates, holding nearly three-fifths of the market revenue in 2022, expected to maintain its lead due to fleet modernisation. Conversely, the LAMEA region is expected to witness the fastest CAGR of 9.3% from 2023 to 2032, driven by the need for efficient regional connectivity.

According to [3], The global demand for up to 150-seat jets is set to be driven by smaller aircraft, totaling 8790 units. Nearly half of these (48%) will contribute to market growth, while the remaining 52% will replace aging aircraft. This shift towards smaller jets aligns with weaker overall demand growth, a preference for short-haul over long-haul routes in traffic patterns, and the industry's increasing emphasis on flexibility, connectivity, efficiency, and transitioning to a decarbonised future through new technology.

4 CONCLUSIONS AND FUTURE WORKS

The aviation industry's current focus on sustainability is linked to the development of new propulsion technologies. In this context, the European EFACA project is developing a hybrid turbine-electric propulsion system with fuel cells. This is a regional aircraft with up to 80 seats and a range of 1000 km.

In addition to the design of the aircraft, it is important to analyse its potential market. For this, it is essential to know the behaviour and the fundamental characteristics of the markets that will be changed by its introduction. The main objective of this paper is to develop such an analysis, considering the figures and trends presented by previous studies and forecasts, as well as scientific papers.

Three markets have been analysed in detail. The first has been the hybrid aircraft market. Then the hydrogen fuel cell market has been deeply analysed. Finally, the main trends and dynamics of the regional aircraft market have been discussed. A distinction has been made between turboprops and regional jets, each of which presents different characteristics.

For each of these market types, the main characteristics have been presented, and figures from specialised studies on their expected growth and value have been provided. In addition, the different needs in different regions have been analysed and expected growth figures have been presented. The impact of the COVID-19 pandemic on international aviation has been significant, with differences between markets. These effects and their recovery trends have also been identified for the markets analysed.

Despite the possible evolution and perspectives of the different global markets considered, it is necessary to address the potential number of aircraft that could be replaced by the proposed hybrid model. This assessment requires a detailed analysis of the current route’s operation and actual market segmentation, because as already discussed, the regional market has experienced significative changes in the last years. The magnitude of these changes, the transformation in the regional market and the adaptation of airlines operation to cover this market in a more efficient way needs to be characterised. This will be the next step. Using the key figures presented in this study, a detailed numerical analysis will be carried out, considering updated global passenger data. The objective will be to calculate the number of aircraft expected in the coming years, to know which aircraft can be replaced by the proposed EFACA design and to make assumptions about its implementation. The trends, market drivers and expected market development figures presented in this paper will be crucial for the further study and will serve as a basis for the proposed numerical analysis.

REFERENCES

[1] 'Regional Aircraft | Clean Aviation'. Accessed: May. 31, 2024. [Online]. Available: https://www.clean-aviation.eu/clean-sky-2/programme-overview-and-structure/clean-sky-2-structure/regional-aircraft

[2] IATA, 'Global Outlook for Air Transport A local sweet spot'. Dec. 2023. Accessed: Jan. 10, 2024. [Online]. Available: https://www.iata.org/en/iata-repository/publications/economic-reports/global-outlook-for-air-transport---december-2023---report/

[3] Embreaer, 'Embraer Market Outlook 2023', 2023. Accessed: Mar. 20, 2024. [Online]. Available: https://www.embraercommercialaviation.com/marketoutlook/

[4] J. D. Anderson, *Aircraft Performance and Design*. New Delhi,India: Tata McGraw-Hill, 1999.

[5] A. Prapotnik Brdnik, R. Kamnik, M. Marksel, and S. Božičnik, 'Market and Technological Perspectives for the New Generation of Regional Passenger Aircraft', *Energies*, vol. 12, p. 1864, May 2019, doi: 10.3390/en12101864.

[6] Markets and Markets, 'Hybrid Aircraft Market Size, Share, Industry Report, Revenue Trends and Growth Drivers', Aug. 2023. Accessed: Feb. 10, 2024. [Online]. Available: https://www.marketsandmarkets.com/Market-Reports/hybrid-electric-aircraft-market-184129847.html

[7] Allied Market Research, 'Hybrid Aircraft Market Size, Share, Competitive Landscape and Trend Analysis Report, by Aircraft Type, by Lift Technology, by Mode of Operation : Global Opportunity Analysis and Industry Forecast, 2024-2033', Jul. 2024. [Online]. Available: https://www.alliedmarketresearch.com/press-release/hybrid-aircraft-market.html

[8] S. Tiwari, M. J. Pekris, and J. J. Doherty, 'A review of liquid hydrogen aircraft and propulsion technologies', *Int. J. Hydrog. Energy*, vol. 57, pp. 1174–1196, Feb. 2024, doi: 10.1016/j.ijhydene.2023.12.263.

[9] D. Forsberg, '2024 Aviation Industry Review & Outlook', PwC, Jan. 2024. [Online]. Available: https://www.pwc.ie/reports/aviation-industry-review.html

[10] 'First ATR 72-600F Aircraft Delivered to FedEx Express', FedEx Newsroom. Accessed: June. 11, 2024. [Online]. Available: https://newsroom.fedex.com/newsroom/united-states/first-atr-72-600f-aircraft-delivered-to-fedex-express

[11] R. Jaworowski, 'Market Growth Forecast for Regional Aircraft Sector', Flight Plan. Accessed: April, 15 2024. [Online]. Available: https://flightplan.forecastinternational.com/2023/08/07/market-growth-forecast-for-regional-aircraft-sector/

[12] ATR, 'ATR: Turboprop market forecast 2022-2041', 2022. [Online]. Available: https://www.atr-aircraft.com/home/turboprop-market-forecast-2022-2041/

[13] Allied Market Research, 'Regional Jet Market Size, Share, Competitive Landscape and Trend Analysis Report, by Platform, by Seating Capacity, by Maximum Take-off Weight : Global Opportunity Analysis and Industry Forecast, 2023-2032', Jun. 2023. [Online]. Available: https://www.alliedmarketresearch.com/regional-jet-market-A107604