ELectric Innovative Commuter Aircraft

D2.1 Economic Feasibility Study for a 19 PAX Hybrid-Electric Commuter Aircraft

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Table of contents

1 Executive summary

The overall question that guides this economic feasibility study for ELICA (ELectric Innovative Commuter Aircraft) is to assess whether the aviation market is ready for a new 19-seater aircraft commuter design. This research question can be answered positively.

Classic market for 19-seater aircraft is not considered as attractive, but with Regional Air Mobility (RAM) i.e. the concept of utilising the point-to-point connection of airfields to reduce travel times significantly (especially for business travellers) and thin-haul air cargo services as increasingly promoted by AmazonAir to further reduce delivery by 50 % new business segments provide sufficient upside potential for new aircraft. Especially the latter point is supported by the new development of the Cessna SkyCourier with FedEx as an anchor customer. Potential cost savings due to a hybrid design (technically and regulative) provide a further plus. With Scotland and Norway two countries are heavily pushing electric aviation and can be considered as initial markets.

A dense network of airfields covering Europe and the US is ready for use and can help to realise RAM services as well as thin-haul air cargo. About 99 % of US population lives within 30 km distance to an ELICA-feasible airfield, also Europe is with a respective share of 77 % ready for this new mode of transport. A transport simulation was executed for the German market and found out that ELICA-services could reach a market share within business trips of about 30 %, leading to an average mission distance of 370 km while assuming an average cruise speed of 375 km/h and a price per revenue passenger kilometre (RPK) of 0.53 € (fully in line with current pricings).

Moreover, a business case for ELICA from an operator perspective is executed. Assuming a utilisation rate of 75 %, about 1,380 flight hours will be done p.a. Cost are assessed to be about 930 € per flight hour, 495 € per revenue mission, and 505,000 € of annual fixed cost – assuming a hybridisation of 15 %. A total annual expenditure of about 2.6 million € is met by revenues of about 2.9 million € leading to a profit of 313,000 € (10.7 %). All derived performance measures are in line with current benchmark figures. Strongest cost drivers that can be influenced by the design are of course energy consumption, but also maintenance efforts for the overall aircraft and the engines. An initial and conservative market assessment postulates an overall market demand for Europe and the US between 240 and 710 aircraft – for RAM purposes only. Annual production rate to satisfy this market is assessed to 28 to 85 aircraft p.a. Baseline is an ELICA market share of between 5 to 15 %.

Overall the economic feasibility study supports a new design of a hybrid electric 19-seater commuter aircraft as new market segments can be expected to open-up and a positive business case can be provided.

2 References

2.1 Abbreviations

Table 1: Abbreviations

Abbreviations	Description
AAV	Autonomous Aerial Vehicle
BBSR	German Federal Institute for Research on Building, Urban Affairs and Spatial Development
BMVI	German Federal Ministry of Transport and Digital Infrastructure
B-N	Britten-Norman
CAA	Civil Aviation Authority
CAGR	Compound annual growth rate
CAeS	Cranfield Aerospace Solutions
DOA	Design Organisation Approval
EASA	European Union Aviation Safety Agency
EU-ETS	European Union Emission Trading System
EIS	Entry Into Service
FAA	Federal Aviation Administration
ft	feet
GA	General Aviation
GAMA	General Aviation Manufactures Association
GDP	Gross Domestic Product
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
ICCT	International Council on Clean Transportation
KPI	Key Performance Indicator
MEDEVAC	Medical evacuation
MTOM	Maximum Take-Off Mass
NGO	Non-Governmental Organisation
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
OD	Operational Day
ODAM	On-Demand Air Mobility
OEM	Original Equipment Manufacturer
p.a.	Per annum
PAX	Passengers approximated
RAM	Regional Air Mobility
RPK	Revenue Passenger Kilometre

Abbreviations	Description
STC	Supplemental Type Certificate
TAS	True Air Speed
TLAR	Top Level Aircraft Requirements
USA	United States of America
VoTTS	Value of Travel Time Savings
WHO	World Health Organization

2.2 List of figures

2.3 List of tables

3 Introduction

The aviation industry is changing with rapid pace. Because of continuous globalisation and a growing wealth and world population that lives more connected than ever, air traffic is projected to double in the next 20 years. The International Air Transport Association (IATA) predicts in different scenarios a growth of up to 150 % in a scenario including market liberalisation and policy stimulus. However, the standardisation body International Civil Aviation Organisation (ICAO) has set out the aim to cap CO_2 emissions on a 2020 level to achieve a carbon neutral growth from there on. This target is only realistic with strong regulatory forces pushing for a high CO_2 price or banning aircrafts without certain emissions standards altogether.

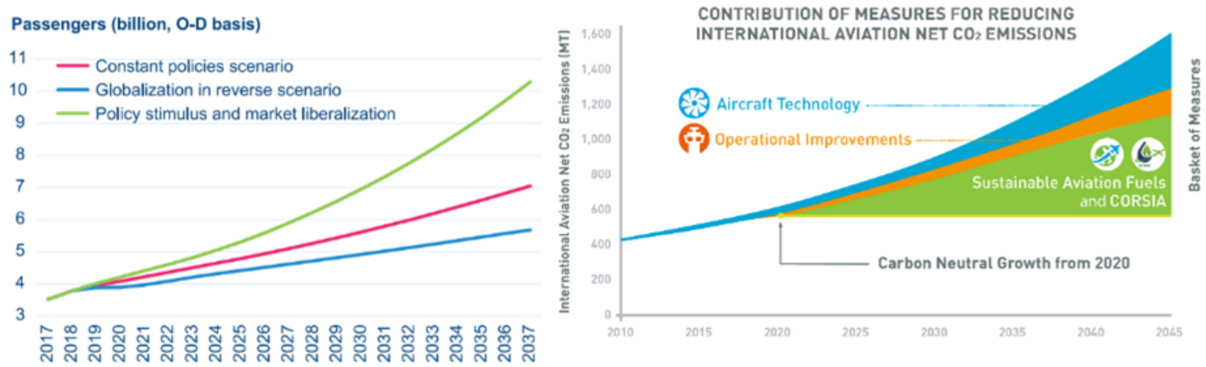

Figure 3-1: Passenger growth scenarios and predicted CO_2 emission scenarios © IATA, ICAO

In light of increasing environmental awareness, regulatory standards are already in place or are going to be implemented in the future. For example, in 2019 a European Citizens' Initiative (ECI) was launched to introduce a tax on aviation fuel, which is currently tax free in all but one country in the EU. Additionally, beginning in 2012, European aviation is taking part in the European emission trading scheme.

This means there will be a strong competitive advantage for more efficient aircraft and more efficient transport in general. In this study the transport system and the economic feasibility for hybrid-electric commuter aircraft is analysed to contribute to future CO_2 savings within aviation.

To reduce the emissions of regional commuter aircraft there are several evolutional technological steps possible but most of them only provide a potential for 15 % emission reduction over the next decade, since they still rely on conventional kerosene fuel. Those improvements are not enough to achieve the goals stated by the aviation industry and politicians all over the world. Therefore, revolutionary technological solutions have to be considered which fundamentally change the propulsion architecture in aviation. Among those are solutions that have been very successfully applied in other transport sectors, for example the hybrid electric propulsion in the automotive sector, of a hybrid electric propulsion. Electric energy is broadly available and already to a great extent generated by renewable sources, which will further increase over time. Furthermore, electric motors and their peripheral power supply are very efficient and by now have achieved power densities suitable for aircraft propulsion. However fully electric powertrains are still far from market entry in most aircraft applications. The reason for that is the vast difference in specific energy density provided by state-of-the-art lithium ion battery versus kerosene fuel. The latter provides 12,500 [Wh/kg] while lithium ion battery top out at around 300 [Wh/kg] a ~42- fold difference. Additionally, for a typical twin engine 19-seater aircraft, the turboprop engine provides a shaft power of around 0.6 MW and consumes during a 220 nm mission a quantity of fuel corresponding to an energy amount of 6 MWh which corresponds roughly to 20 tons of Li-Ion battery. These physical constraints cannot be overcome. In a hybrid propulsion system on the other hand, it is possible to provide a significant amount of mission energy with electrical energy and use synergies to downsize the fossil fuel powertrain and use it to cover all the reserves required by regulations.

Certification is one of the most important aspects in the aircraft development process. The regulatory framework sets the stage for the possible technical performance. The majority of aircrafts discussed here are certified in the commuter category, some are certified in the normal category. These categories are defined via the FAA Federal Aviation Regulations - Part 23 or the EASA Certification Standard (CS) - 23. The FAA is the Federal Aviation Administration in the United States, whereas EASA, European Aviation Safety Agency assumes the same role in the European Union. The standards are very similar, and the certification categories haven been as stated below since the seventies. However, recently in 2017 a restructuring of FAR23/CS23 took place, with all aircraft certified in one category. This new category definition applies to none of the benchmarked airplanes but will be briefly mentioned. CS 23.2000 states that the certification specification prescribes airworthiness standards for aeroplanes in the normal category. CS 23.2005 states: "Certification in the normal category applies to aeroplanes with a passenger seating configuration of 19 or less and a maximum certified take-off mass of 8,618 kg (19,000 pounds) or less."

Traditionally both standards state two categories, dependent on weight, number of passenger seats and number of engines. The first category includes single engine aircraft with a maximum take-off mass (MTOM) of less than 5,670 kg (12,500 lb) and 9 or fewer passenger seats. The second category, the commuter category, includes multiengine aircraft with a maximum take-off mass (MTOM) less than 8,618 kg (19,000 lb) and 19 or fewer passenger seats. Airplanes in the commuter category can be used for flying in Visual Flight Rules (VFR), and Instrumental Flight Rules (IFR) both day and night and in known icing conditions (FIKI) if they are equipped so. However, via the Special Federal Aviation Regulation No. 23, published by the FAA it is possible to certify multiengine airplanes with more than 10 seats in the normal category if special requirements are met.

There are about 2,300 aircrafts in the commuter category currently flying.[1] Most of the designs originate in the seventies to nineties of the last century, during a boom time for this type of aircraft. Since then oil prices have increased and regulation has intensified which meant that a lot of operating cost advantages 19-seaters had over bigger aircraft classes have disappeared. The MTOM of these types range from 5,670 kg to 8,618 kg as described in the regulatory framework paragraph. All successful types use a traditional monoplane design. With a major distinction between the low wing and the high wing design. Tail configurations can vary from the conventional tail, a cruciform tail or the T-tail seen for example on the Beechcraft 1900D. Also, some H-Tail configurations are known (PZL M28). All of them are equipped with two turboprop engines, which provides the redundancy that is required by regulatory agencies in most parts of the world for commercial operations. For safety reasons, as well as for pilot training all of them have two pilot seats and all of them can be ordered with 19 passenger seats.

[1] GRIMME, Wolfgang, et al. Evaluation of the Market Potential and Technical Requirements for Thin-Haul Air Transport. 2019.

Figure 3-2: Selection of 19-seater commuter aircraft: Beechcraft 1900D, Do 228NG, DHC-6-400 Twin Otter (left to right) © Wikipedia, Jetphotos

Pictured here are three typical examples with high production numbers (cf. Figure 3-2). First, the Beechcraft 1900D is shown, which was produced between 1982 and 2002. Although it has gone out of production it was highly successful with 695 aircrafts built. It is a low-wing design of primarily metal construction with a retractable tricycle landing gear. All models feature a pressurised cabin, while the cabin height in the D model is significantly increased to enable upright walking for most people. The model features 19 seats and has an MTOM of 7,688 kg. Second, the Dornier 228 NG is depicted. This aircraft is originally designed by the German company Dornier and is now being produced by Swiss company RUAG. The aircraft has a MTOM of 6,400 kg and is a cantilever high-wing aircraft of all-metal construction with retractable landing gear. Third, the Viking Air DHC-6-400 Twin Otter is shown, which is a versatile 19 passenger Short-Take-off and Landing (STOL) aircraft, with an MTOM of 5,670 kg. This is within the limit of 12,500 lb MTOM, so it is certified in the normal category. However, this aircraft typically flies commuter category missions. It is used around the world for various missions and because of its STOL abilities on short and unpaved runways especially. However, there is no pressurised cabin present in the DHC-6-400 which limits the pressure altitude to 10,000 ft without passenger oxygen.

The purpose of this study is to lay the economic foundation for the technical development of ELICA and to investigate the question, whether it is time for a new electro-hybrid 19-seater commuter aircraft design. To answer this question, firstly an introduction to the overall turboprop market is provided, followed by an analysis of the historical and present situation for 19-seaters in chapter 4.

A broad range of topics are covered in chapter 5 to answer the question why it is time for a new design. Two new business segments are introduced (RAM and thin-haul air cargo services) and both technical and regulative upside potential for electro hybrid aircraft in terms of cost savings are discussed. Two deep dives on the relevance of aircraft noise and requirements for aircraft interieur are executed, followed by two case studies of forming lead markets for electric aviation (Scotland and Norway). Finally, the feasibility of a market entry of a new player is demonstrated by introducing the example of Cirrus Aircraft for the piston engine aircraft market.

To provide a clearer picture of available airfield infrastructure in Europe and the US as well as competitive advantages of ELICA towards other transport modes (car, train and CS-25 aircraft), an infrastructure and transport study is executed in chapter 6. Important parameters such as average mission distance and transport demand are estimated.

A positive business case is crucial to assure a market success of ELICA. Hence, a business case is calculated in chapter 7 from the perspective of an operator. Utilisation rates, cost of aircraft operation as well as revenues and profits are discussed. Moreover, main cost drivers are analysed and a sensitivity analysis is carried out. The chapter closes with an initial market sizing for ELICA in terms of total aircraft needed to satisfy the transport demand derived from chapter 6.

This study closes with a summarising conclusion to provide an overall picture of the economic feasibility of ELICA and to answer the question, whether it is time for a new 19-seater aircraft commuter design.

4 ELICA market study

All the existing 19-seater commuter aircraft rely on turboprop engines and are certified according to the CS-23 norm of EASA and/or FAR-23 norm of FAA. Both aircraft types can be grouped within the market segment 'General Aviation' (GA). GA covers a broad range of small aircraft types. Important segments are single- and multi-engine piston aircraft (e.g. Cessna 147 or Diamond DA-42), business jets (e.g. Gulfstream G280 or HA-420 HondaJet) and turboprop aircrafts.

Most sufficient statistical sales data on GA-aircraft is provided by the General Aviation Manufacturers Association (GAMA), which covers almost all relevant aircraft manufactures, aircraft types and markets. If not declared differently, the data presented in the following is taken from the most recent annual report from GAMA for the year 2018[2].

As far as data for turboprop aircraft is available, it is presented here. For comparison, data for piston engine aircraft is provided, too. The turboprop aircraft segment can be divided in single- and multi-engine aircraft and ranges from aircraft for five passengers, such as the Socata TBM 900, to 19-seater commuter aircraft such as the DHC-6-400 Twin Otter.

Hence, 19-seater commuter aircraft represent a niche within the niche-market of turboprop aircraft. Nevertheless, general market data on turboprop aircraft can provide insights on the overall market situation and is hence presented in section 4.1. Section 4.2 focuses on the market segment of 19-seater commuter aircraft and presents information on both the market history and the present situation. Finally, an interim conclusion is given.

4.1 Turboprop and piston engine aircraft market

By far the most piston and turboprop aircraft are registered in the USA, followed by further countries with a large national territory (e.g. Canada or Australia) and comparable large and developed countries such as the UK, Germany or France. The estimated worldwide distribution of piston and turboprop aircraft is given in Figure 4-1.

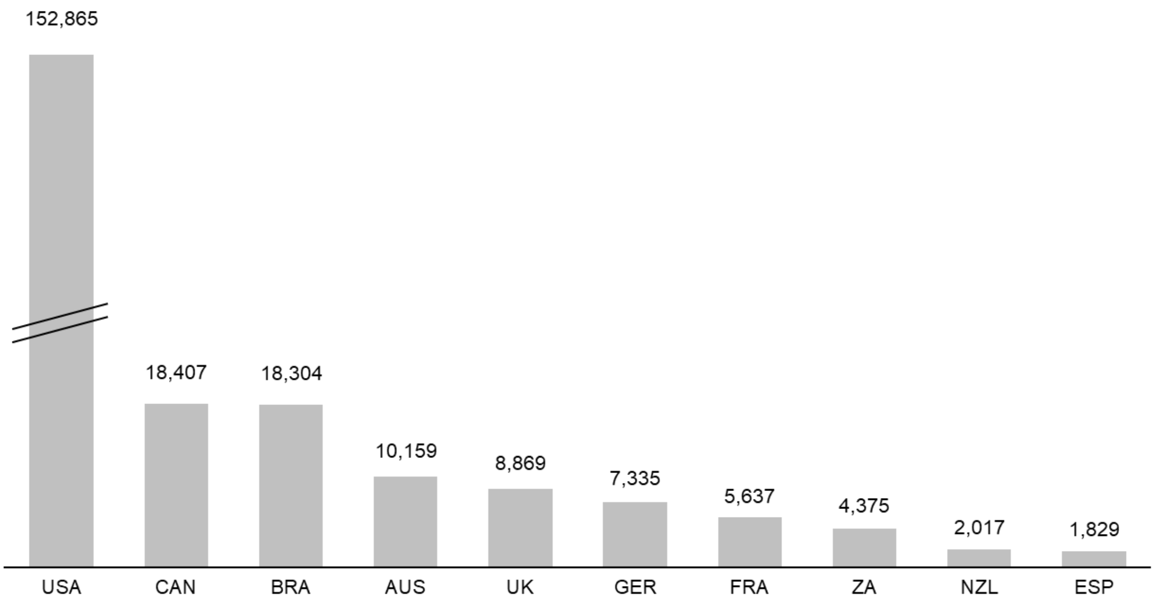

Figure 4-1: Number of piston and turboprop aircraft for the top 10 countries as of 2018

2 2018 Annual Report of GAMA: https://gama.aero/documents/2018-annual-report-v2/

There is no sufficient statistical data for Russia or India. A comparable low number of GA-aircraft are registered in China (about 1,000) because vast parts of the lower airspace are restricted for military use only.

Focusing on the most important US-market, the number of registered piston and turboprop aircraft experienced a significant downfall from 2010 to 2013, but it is recovering since then and almost reached the level of 2012 again (cf. Figure 4-2). The vast majority of aircraft is powered by a piston engine. About 7 % of the fleet are turboprop aircraft. Due to the strong downfall until 2013, the overall market numbers are declining with a compound annual growth rate (CAGR) of -1.5 %. However, the turboprop aircraft segment is by far not as strongly affected as the piston engine segment. On the contrary, in a GAMA market forecast up to the year 2027, turboprop aircraft registered in the USA are expected to grow with a CAGR of 0.33 %.

This is also reflected by the average age of the operated aircraft, which is with 46.2 years quite high for single engine piston aircraft. Single-engine turboprop aircraft have an average age of only 14.2 years, multi-engine turboprop aircraft are on average about twice as old as single-engine ones (29.0 years).

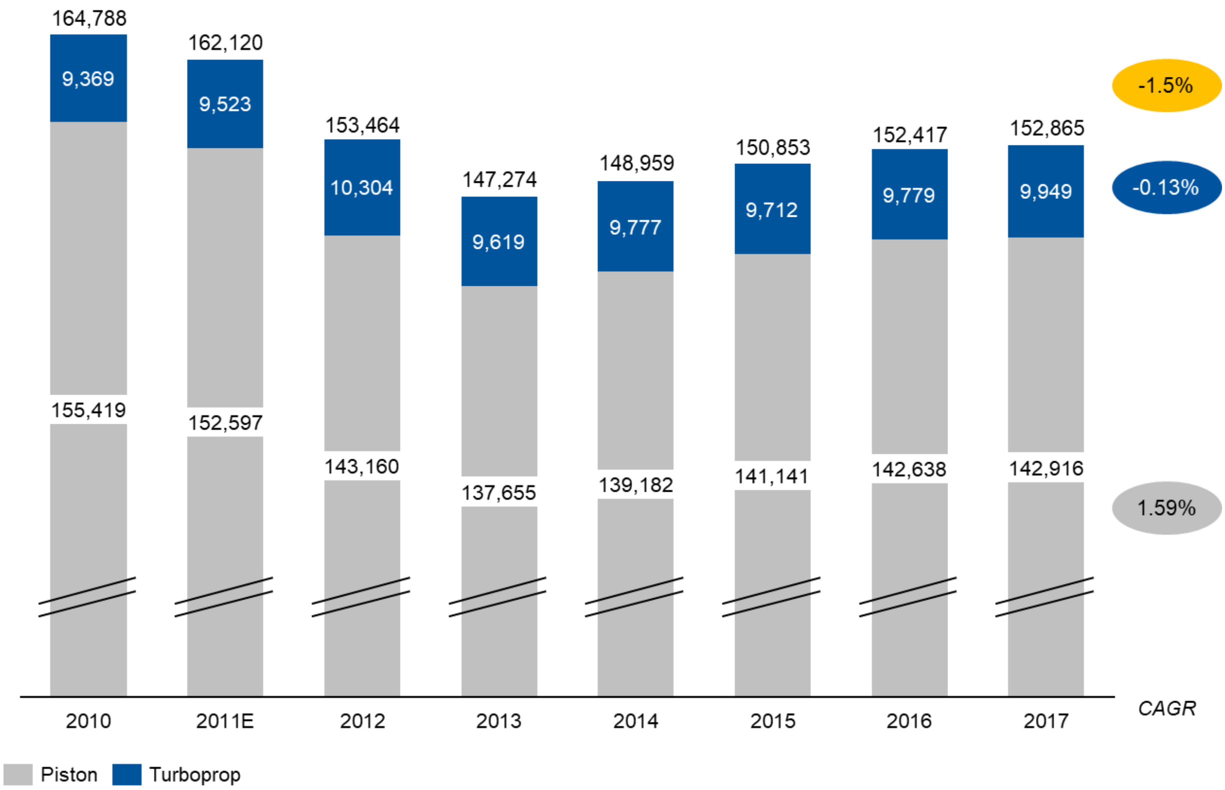

Figure 4-2: US aircraft fleet according to engine type, 2010 to 2017

Worldwide sales of piston engine and turboprop aircraft are growing strongly, mostly driven by the turboprop aircraft sales (CAGR of 6.32 %). In the period from 2010 to 2018, 559 turboprop aircraft were sold on average annually worldwide annually which is about half of the sold piston engine aircraft (1,199). As presented in Figure 4-3, annual sales are strongly fluctuating but tend to grow solidly. It has to be added that only turboprop sales in the GA category are included, meaning that bigger turboprop aircraft like the ATR 42/72 or de Havilland Dash 8 are excluded. This also holds true for the following statistics in this section.

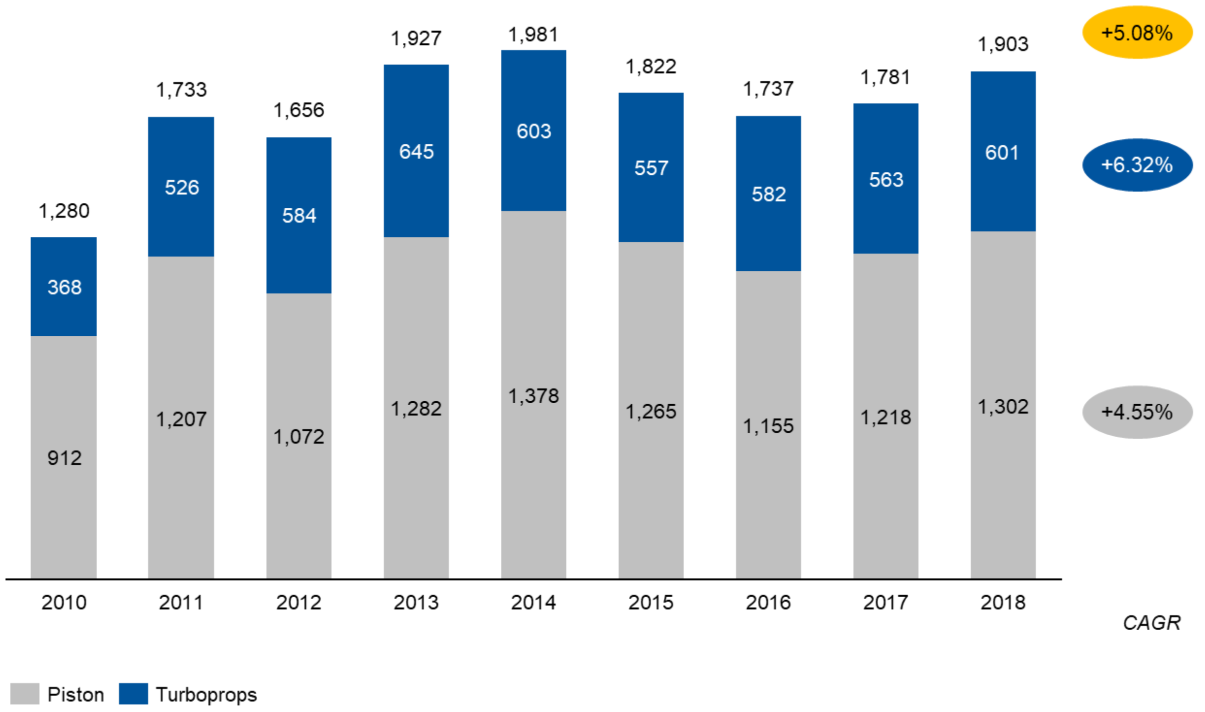

Figure 4-3: Piston engine and turboprop aircraft sales worldwide in GA, 2010 to 2018

The USA are also the most important producer of turboprop aircraft with an average yearly production of 418 aircraft, compared to only 131 in Europe and a neglectable number of turboprop aircraft produced in the rest of the world as shown in Figure 4-4. Market growth is more or less completely provided by an extension of US production rates.

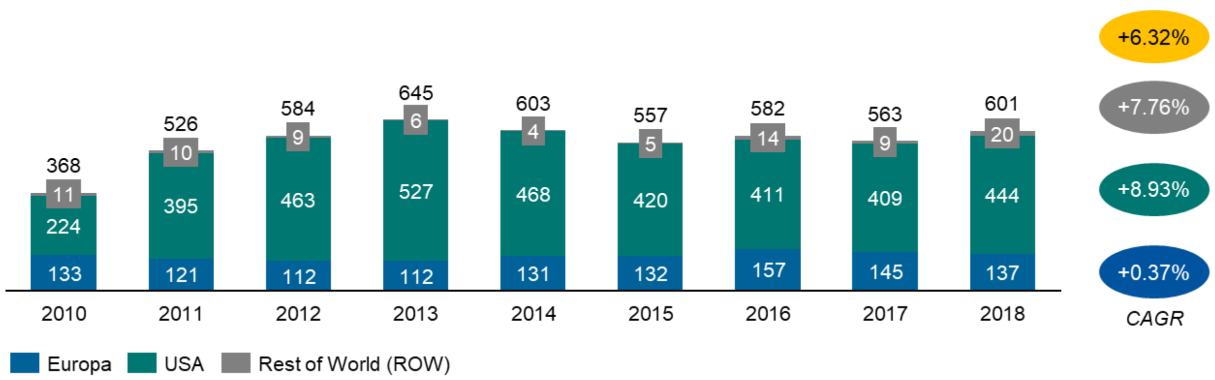

Figure 4-4: Turboprop aircraft manufactured by world region, 2010 to 2018

Most of the turboprop aircraft are sold with an annual average of 294 aircraft in North America, as shown in Figure 4-5. Further strong markets are Latin America and the Asia-Pacific region, followed by Europe and the Middle East and Africa. Overall, the strongest market growth can be reported for North and Latin America with 8.25 % and 6.5 % respectively.

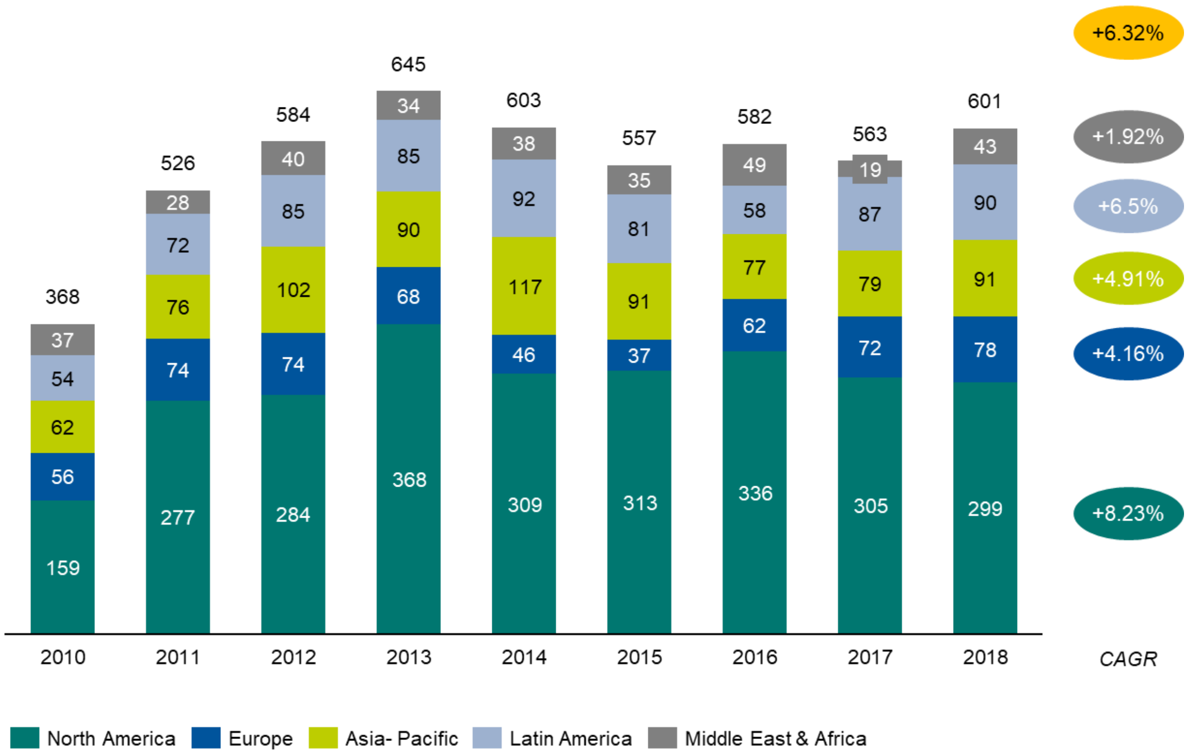

Figure 4-5: Turboprop aircraft sold worldwide by region, 2010 to 2018

Taking a deeper look on the turboprop manufacturers (Figure 4-6), 96 % of the market are distributed among seven players. The most successful companies, according to sold aircraft in 2018, are Textron Aviation (186 turboprop aircraft or 31 %), Air Tractor (141 turboprop aircraft or 23 %) and Pilatus (83 turboprop aircraft or 14 %)).

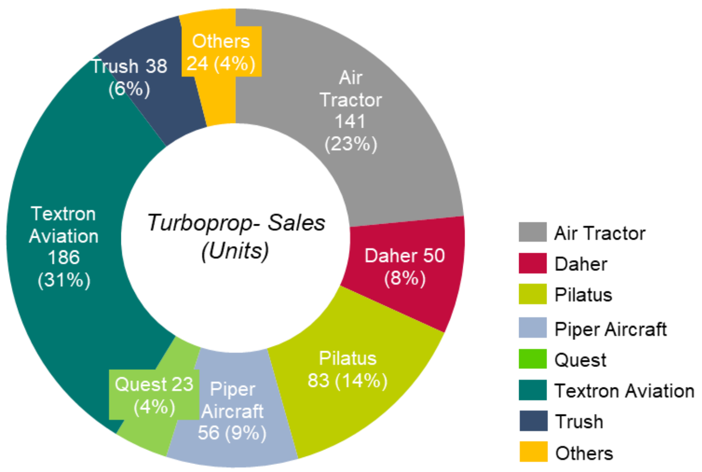

Figure 4-6: Turboprop aircraft sales by manufacturer in 2018

The turboprop aircraft sales market was worth about 1.8 billion US-dollars in 2018. On average, 1.6 billion US-dollars were earned p.a. in the period 2010 to 2018. Compared to 590 million US-dollars of average revenues generated with piston engine aircraft, the market for turboprop aircraft is almost three times as big as the market for piston engine aircraft due to the significantly higher unit prices. Overall CAGR is 5.19 %, which is mainly driven my strongly increasing revenues of piston engine aircrafts.

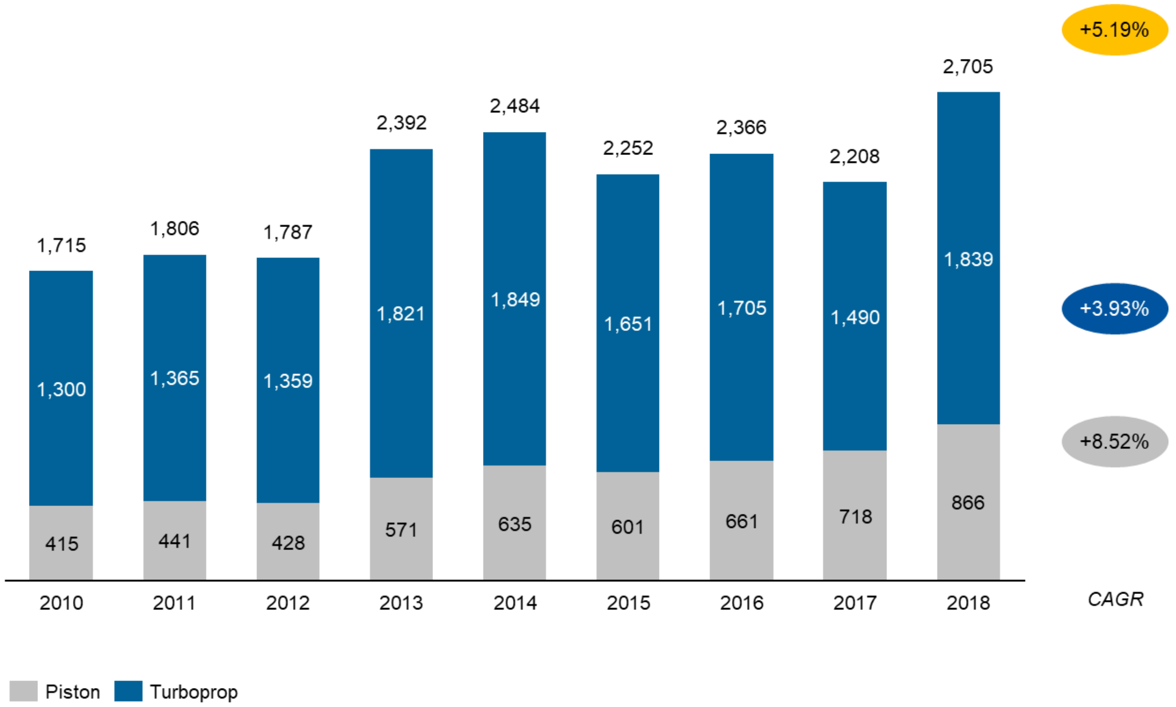

Figure 4-7: Worldwide revenues generated with piston and turboprop aircraft, 2010 to 2018

Revenues of turboprop aircraft manufacturers cannot be provided as all of them build also piston engine aircraft or business jets and include after-market services. Hence, the company revenues cannot provide an indication for the development of the turboprop aircraft market.

4.2 19-seater commuter aircraft market

From the 1960s to the 1980s eleven 19-seater commuter aircraft variants (or comparable aircraft such as the PZL M28 Skytruck (18 seats) or the Harbin Y-12 (17 seats) were introduced to the market, as presented in Table 2. Overall, about 5,500 aircraft were sold up to now. The most successful aircraft in terms of aircraft sold is the Czech LET410 with 1,166 aircraft delivered, representing about 21 % of the entire fleet. About 53 % of all aircraft sold were manufactured by North American or British companies.

As of today, only three separate aircraft are still in production (DHC-6-400 Twin Otter, PZL M28 Skytruck and Do 228 in India and Do 228NG in Germany). Textron Aviation is the only company developing a new 19-seater commuter aircraft – the Cessna SkyCourier 408 with a planned maiden flight in 2020.[3]

Table 2: 19-seater commuter aircraft sold worldwide, sorted by delivered units, 1966 to 2018[4]

Aircraft	Manufacturer	Country	Start of production	End of production	Delivered units
LET410	Let	Czech Republic	1971	2019	1,166
DHC-6 Twin Otter	De Havilland Canada/ Viking Air	Canada	1966	-	959
Fairchild Swearingen Metro	Swearingen	USA	1970	2001	700
Beech 1900	Textron Aviation (Beechcraft)	USA	1984	2004	692
Embraer EMB 110	Embraer	Brazil	1970	1996	500
Bae Jetstream 31/32	British Aerospace	UK	1982	1997	382
Dornier 228 / Do 228NG	Dornier/ Hindustan Aeronautics/ RUAG	Germany	1982	-	363
Antonov AN-28/ PZL M28 Skytruck	Antonov/ PZL	Ukraine/ Poland	1986	-	256
Harbin Y-12	Harbin Aircraft Manufacturing	China	1985	2017	206
Short Skyvan	Short Brothers	UK	1966	1986	145
IAI Arava	IAI	Israel	1973	1993	98

[3] https://cessna.txtav.com/en/turboprop/skycourier

[4] Desk research, DLR final report on 19-seater commuter research project with Bauhaus Luftfahrt

Grimme et al.[5] provide data for the global civil 19-seater aircraft fleet derived from Cirium Fleets Analyzer. The market penetration reached its maximum in the early 1990s with more than 3,200 aircraft operational servicing thin-haul routes for passengers or freight in civil applications (cf. Figure 4-8. Note, about additional 600 19-seater aircrafts were operated in military applications in the early 1990s, which are not considered in Figure 4-8).

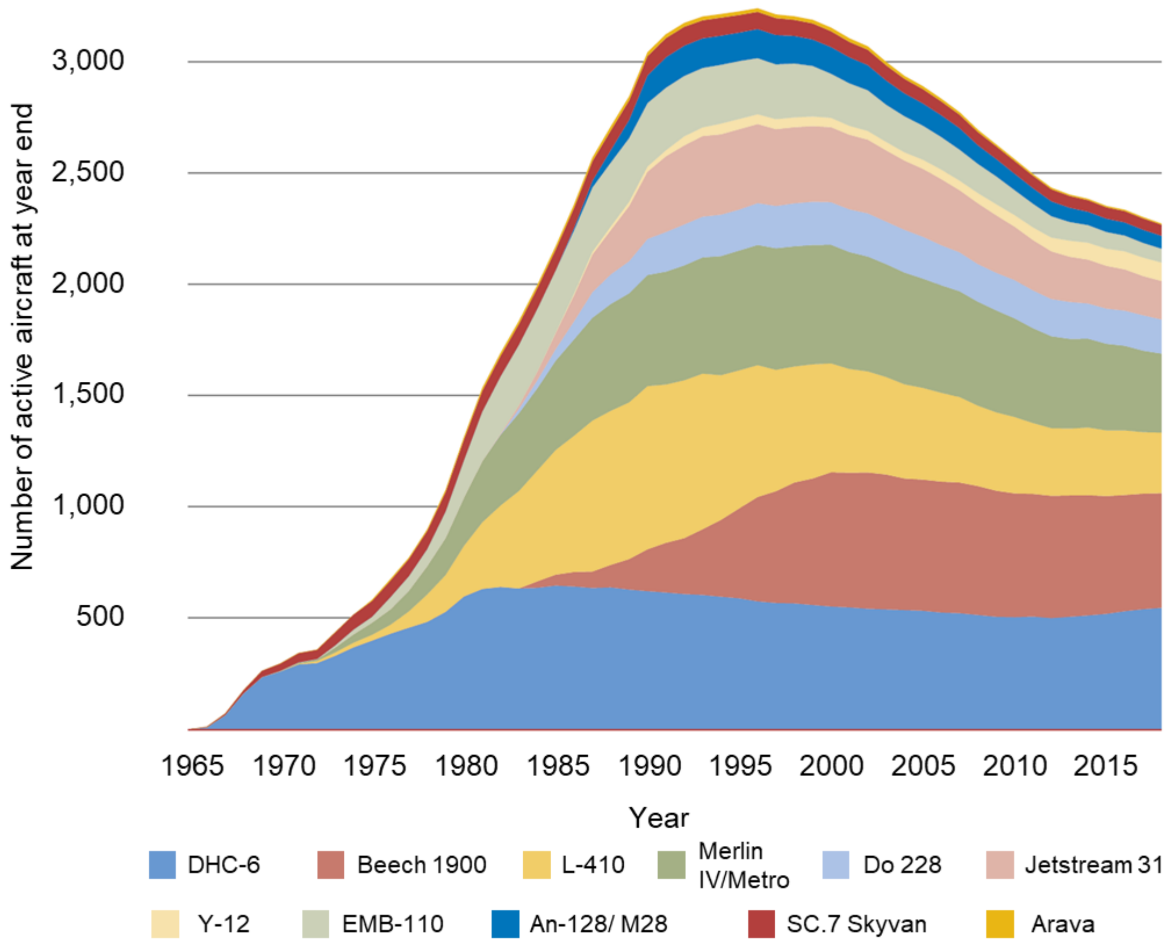

Figure 4-8: Global 19-seater commuter aircraft fleet in civil range. [5]

Since then a strong decline set in, diminishing slightly from 2010 onwards and leading to a fleet size of 2,272 civil aircraft in 2018, i.e. a CAGR of -1.4 %. The authors explain this decline with upcoming low-cost carriers and high-speed rail connections that offer faster and less expensive travel services.

About two thirds of the missions performed by 19-seater commuter aircraft (civil applications) are dedicated to passenger transport and only 14 % to air cargo (cf. Figure 4-9). Other important application fields are parachuting services, business aviation or air taxi.

[5] GRIMME, Wolfgang, et al. Evaluation of the Market Potential and Technical Requirements for Thin-Haul Air Transport. 2019.

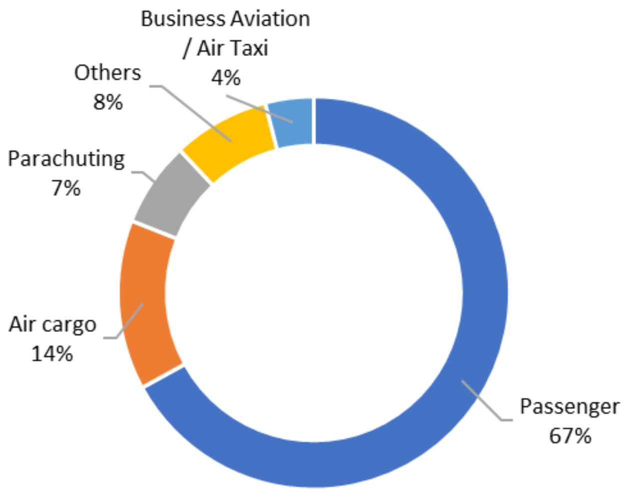

Figure 4-9: Civil missions for 19-seater commuter aircraft[6]

The development of worldwide departures of 19-seater commuter aircraft is given in Figure 4-10. The numbers fell by 500,000 departures or 20 % from 1998 to in 2018 to 20%, representing a CAGR of -13.6 %.

The most important market is North America with more than 50 % of all departures, followed by Latin America, Africa and Oceania. The decline of the worldwide departures of 19-seater commuter aircraft is way stronger than the decline of the worldwide fleet.

Military usage of 19-seater commuter aircraft is comparable to its civil usage, but with a stronger focus on special operations, such as search and rescue or long-distance surveillance. 19-seater commuter aircraft are operated by a broad range of military organisations worldwide. Unfortunately, specific data for military mission types or departures cannot be provided.

6 GRIMME, Wolfgang, et al. Evaluation of the Market Potential and Technical Requirements for Thin-Haul Air Transport. 2019.

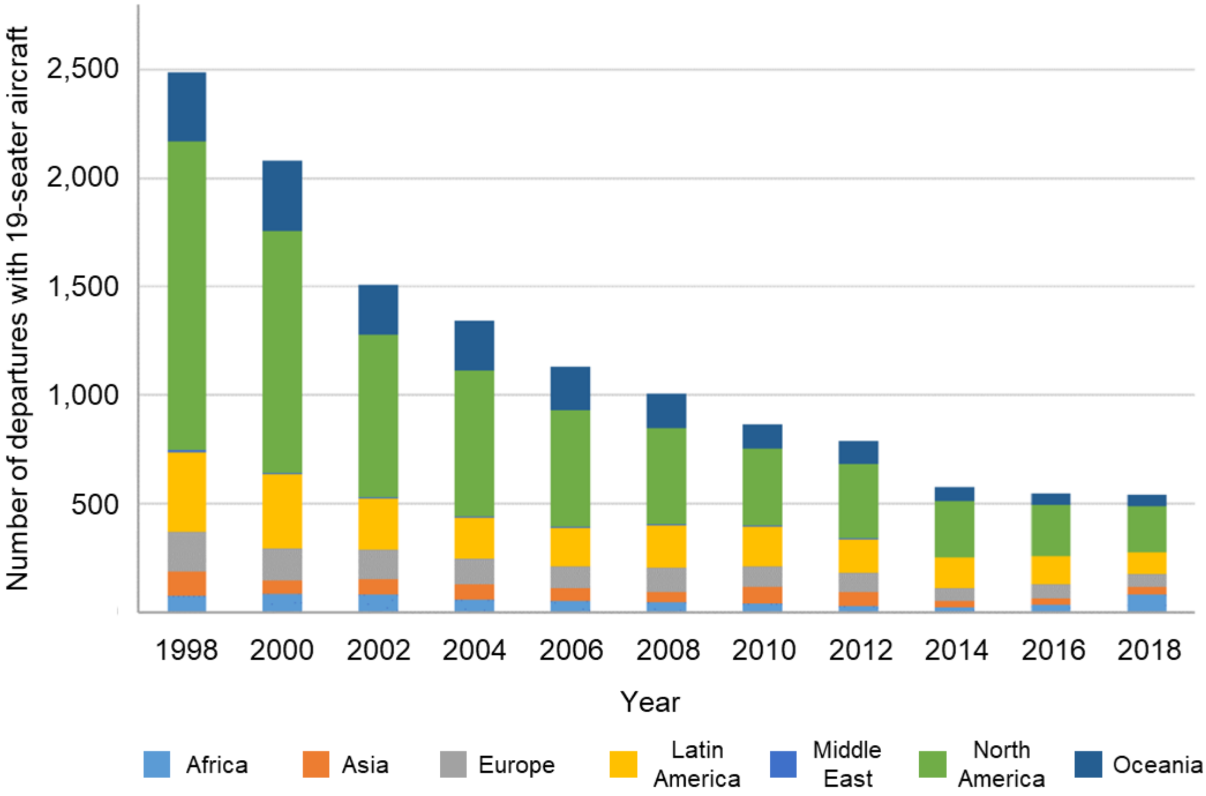

Figure 4-10: Departures of 19-seater commuter aircraft per world region, 1998 to 2018 [7]

4.3 Interim conclusion

In summary, the turboprop market with regards to aircraft sold a niche market even within General Aviation but generates three times the revenues of piston engine aircraft as turboprop aircraft are technically more complex and can easily cost up to 5 or 6 million USD. Nevertheless, it is outperforming the overall market of aircraft sold in terms of relative and absolute growth. Most important sales and production markets are the USA, where also most of the dominant market players are located.

In conclusion, the economic flowering of the 19-seater commuter aircraft market ended in the last century. As of today, only three aircraft variants are still in production and only one new variant is in development. The most common mission type is the passenger transport on fixed routes and most relevant market is still North America.

Hence, the traditional market applications do not provide sufficient demand for further aircraft or new developments. Nevertheless, upcoming changes in transport modes and the skyrocketing air cargo deliveries open-up new market opportunities, which will be discussed in the following chapter.

[7] GRIMME, Wolfgang, et al. Evaluation of the Market Potential and Technical Requirements for Thin-Haul Air Transport. 2019.

5 Why it is time for a new design

Besides the established application areas for 19-seater commuter aircraft, at least two new business segments can be identified which shall be presented in the following: RAM and thin-haul air cargo services. Both markets are not entirely new but can be expected to grow significantly within the coming years. To foster the success of ELICA on those markets, a couple of deep dives are done within this study:

First of all, cost saving potentials due to electrification are summarised as operational cost will be (positively) affected and can level-out or even over-compensate additional cost for electrical engines, batteries or further electronics. Further (economic) upside potential for ELICA may evolve due to increased regulation in terms of CO_2-taxes or subsidies for environmentally friendly aircraft, which is discussed in section 5.4.

As airfields and regional airports will be more frequented in the future, noise is a topic to be considered as well (section 5.5). To ensure a broad range of business segments for ELICA, a flexible aircraft interior should be favoured, to easily adapt to different mission requirements, such as passenger and air cargo transport or special missions (e.g. parachuting, search and rescue or reconnaissance). Potential layouts, their benefits and drawbacks are presented in section 5.6.

Two case studies highlight the relevance of hybrid or fully electric aircraft as such concepts are heavily promoted in Scotland and Norway (sections 5.7 and 5.8). Finally, the company Cirrus Aircraft is introduced to showcase that a successful market entry into General Aviation is possible, if certain aspects are kept in mind. This chapter closes with an interim conclusion given in section 5.10.

5.1 New business segment Regional Air Mobility

According to the goals of ‘Flightpath 2050’, formulated by the European Commission, ’90 % of travellers within Europe are able to complete their journey, door-to-door within 4 hours’.[8] Hofmann et al.[9] derive from those goals a growing demand for commuter aircraft to serve regional airports. This assumption is backed-up by further scholars, such as Sun et al.[10], who analyse the market for more individual air transport within Europe. They estimate the door-to-door travel time for 100 large European cities to the rest of Europe. For the estimation Europe is split up into 200*200 grid cells, by comparing travel times of car, train, CS-25 aircraft and air taxi services. The latter is defined as the transport of small groups of people using aircrafts and airfields or regional airports and is therefore (partly) in line with the goals of ELICA. Their main results are that the car dominates short distances and CS-25 aircraft long distances. The attractiveness of train connections of course heavily depends on the existing infrastructure. Air taxi services or RAM is the preferred mode of transport for distances averaging between 100 and 420 km. Figure 5-1 showcases an according analysis done for the city of Aachen, Germany. The red dots indicate that vast parts of the Netherlands, the east of France and the more rural parts of Germany can be reached quickest by using an air taxi service.

Figure 5-2 (left) presents the relative competitiveness of different modes of transport over distance for Milan, Italy. The advantage of RAM for distances of a couple of 100 km is indicated by the red line. Kreimeier[11] analysed RAM or On-Demand Air Mobility (ODAM) for Germany and derived the demand of more than 40,000 air taxis. The average trip distribution according

8 European Commission, Flightpath 2050. Europe's Vision for Aviation - Maintaining Global Leadership & Serving Society's Needs, Publications Office of the European Union, Luxembourg, 2011.

9 Hofmann, Jan-Philipp, et al. ‘A Comprehensive Approach to the Assessment of a Hybrid Electric Powertrain for Commuter Aircraft.’ *AIAA Aviation 2019 Forum*. 2019.

to trip length is given in Figure 5-2 (right). Most trips shall have a length between 100 to 400 km. It has to be highlighted that Kreimeier has analysed the German market for a four-seater aircraft and also found out that the demand itself is quite cost sensitive. ELICA will have a larger passenger capacity and will therefore focus on more frequented routes than the air taxi services introduced by Sun and Kreimeier. Therefore, the market for ELICA can be understood as a part of the air taxi markets introduced by Sun and Kreimeier.

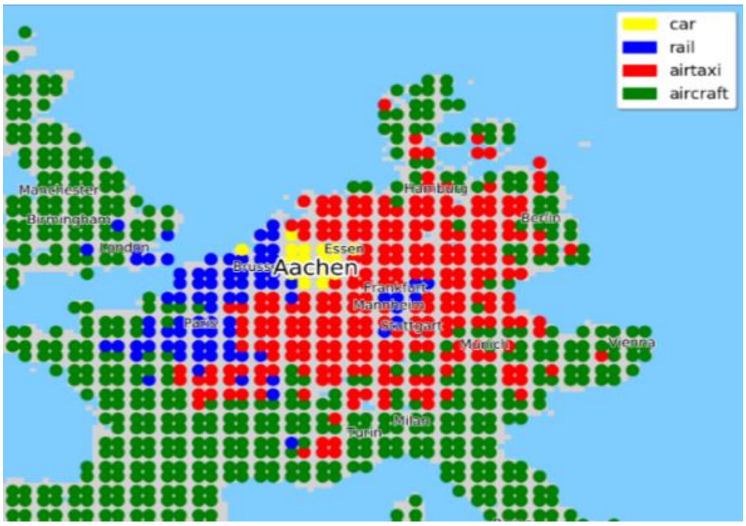

Figure 5-1: *Accessibility competition for Aachen, Germany – mode of transport with shortest travel time over distance*[10]

Their results indicate a demand for thin-haul air services in more rural parts of Europe that are not well enough connected to the main transport modes such as train, car or CS-25 aircraft.

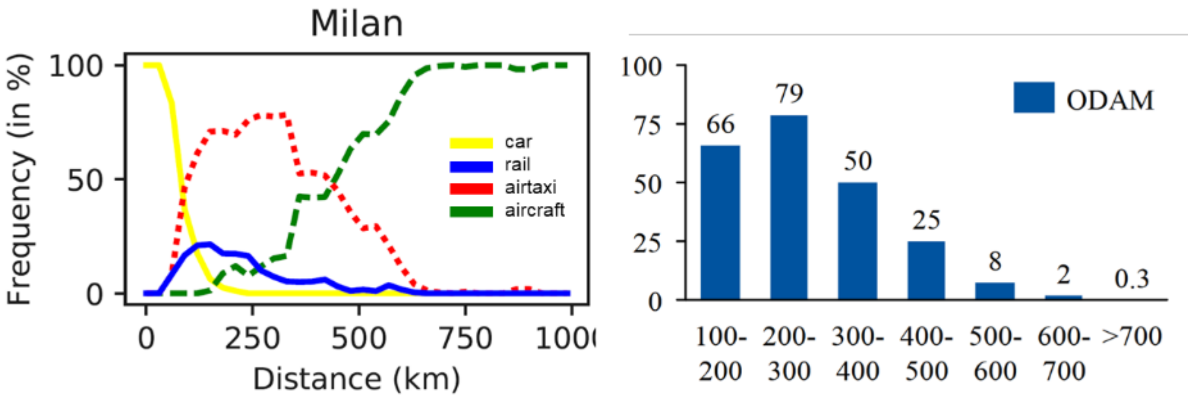

Figure 5-2: Left: Relative competitiveness of different modes of transport over distance for Milan, Italy; Right: Estimation of ODAM trip length distribution for Germany[10] [11]

The situation in Germany is presented in Figure 5-3 and taken from the accessibility model of the German Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR). It shows the average time per county to reach a federal motorway access, a train station with long-distance service and a large airport. Long travel times are coloured red. It is

[10] SUN, Xiaoqian; WANDELT, Sebastian; STUMPF, Eike. Competitiveness of on-demand air taxis regarding door-to-door travel time: A race through Europe. *Transportation Research Part E: Logistics and Transportation Review*, 2018, 119. Jg., S. 1-18.

[11] Phd thesis Kreimeier, Michael, RWTH Aachen University, ILR: Evaluation of on-demand air mobility concepts with utilisation of electric powered small aircraft, 2019.

obvious that large parts of Germany are badly connected with established modes of long-distance transport. A similar situation can be assessed for all larger countries in the EU.

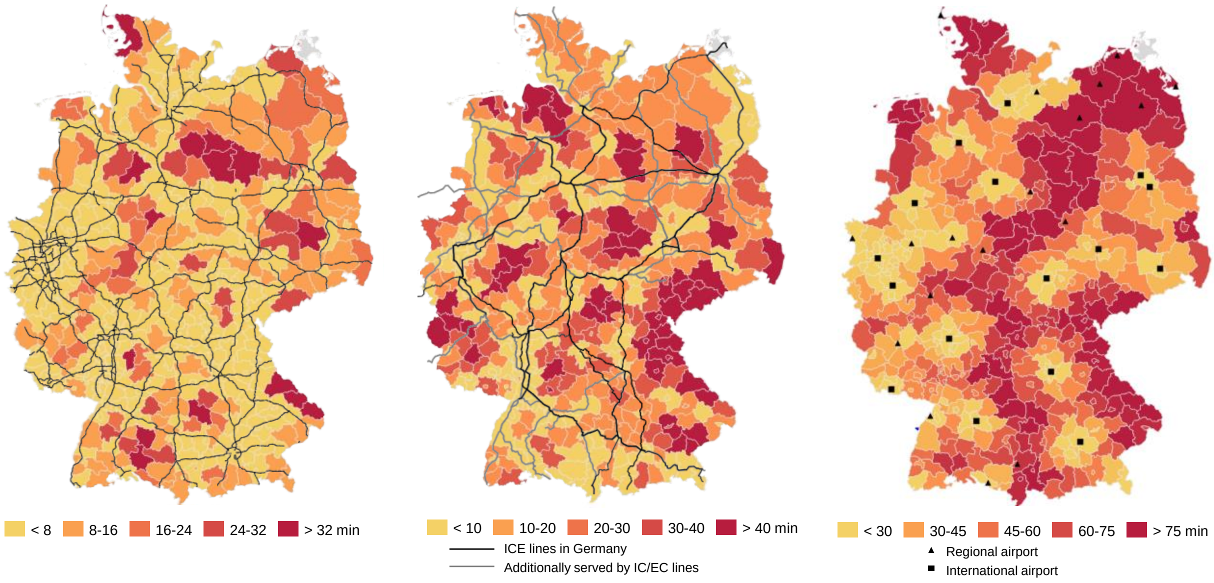

Figure 5-3: Accessibility model BBSR for the transport modes car, fast train and CS-25 aircraft[12]

Moreover, existing airport infrastructure is not fully exploited as indicated in Figure 5-4.

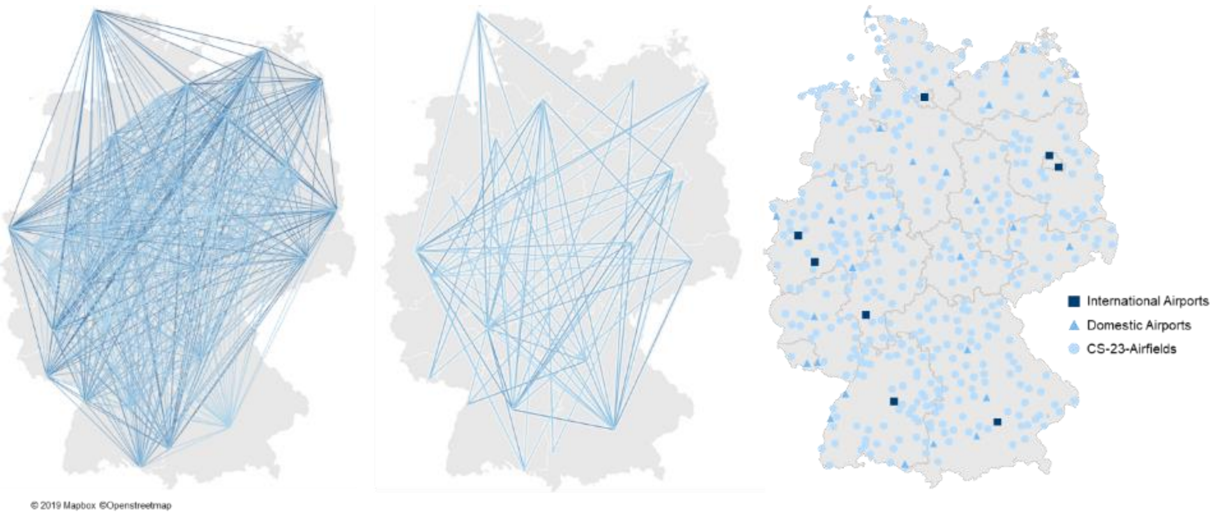

Figure 5-4: Left: Theoretically possible CS-25 connections; middle: actually offered connections; right: airports and airfields available in Germany[13] [14]

The map of Germany on the left provides the theoretically possible connections between international airports and the middle map gives the currently offered connections. Reasons might be fully utilised airports (availability of start and landing slots), competing train lines (e.g. Hamburg-Berlin or Berlin-Munich) and the utilisation of large aircraft that require a certain demand on a given route to be profitable.

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12 Accessibility model of BBSR: https://www.bbsr.bund.de/BBSR/DE/Raumbeobachtung/UeberRaumbeobachtung/Komponenten/Erreichbarkeitsmodell/erreichbarkeitsmodell_node.html

13 Air s.Pace desk research; flight plans of major German airlines, airfield and airport databases

14 Right graphic is copyright of e.SAT GmbH

Hence, the fulfilment of the goals of the European Commission to reduce the door-to-door travel time to four hours can only be reached if domestic airports and airfields are addressed by thin-haul services. It can be assumed that both small air taxis with four PAX-seats as well as larger aircraft in the 19-seater commuter class can help to realise this goal. The German map on the right-hand side indicates that the infrastructure is already there and can be exploited. In Germany, more than 350 airfields and airports are operated. According to Kreimeier[11], about 80 % of the German population lives within a radius of 20 km around all airfields and airports.

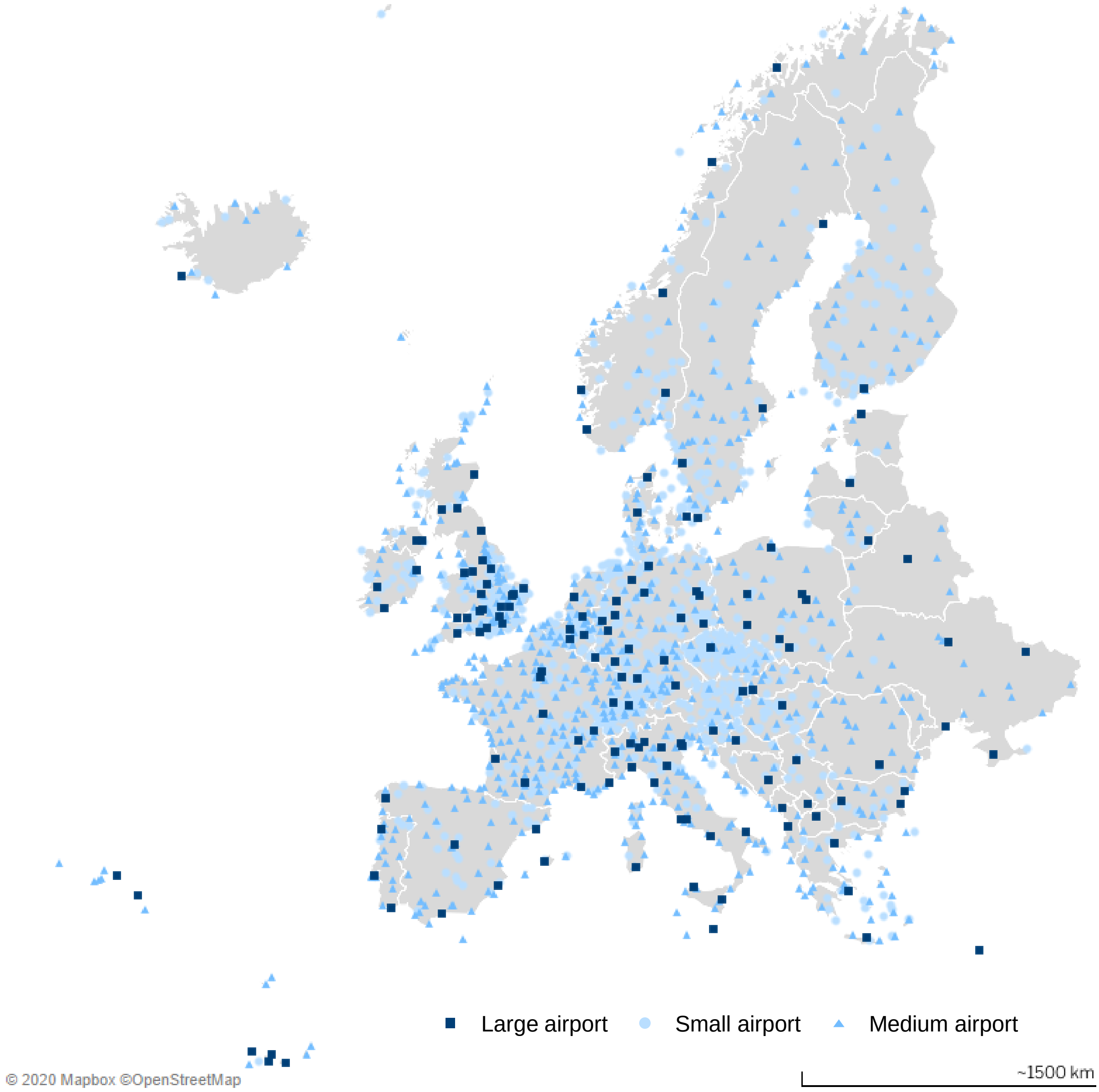

Figure 5-5: Overview of available airports and airfields in Europe based on ourairports.com open-source database [13]

Consequently, the airfield infrastructure will play a key-role to realise the travel time reduction. Figure 5-5 showcases that not only Germany operates a dense infrastructure of airfields but also many other countries in the European Union do so, such as France, Italy, Spain, Austria, the Czech Republic, Poland and also the UK and Switzerland.

A sophisticated airfield infrastructure can be found in other parts of the world as well (cf. Figure 5-6), e.g. the USA, Australia, Oceania, and parts of South America (especially the Caribbean area) and parts of the south of Africa and India.

To provide a better understanding of the actual airfield network in selected member states and the USA an analysis will be provided in the Top Level Aircraft Requirements (TLAR) study (ELICA Deliverable 2.2). The goal is to ensure an aircraft design that is ready to approach airfields with shorter runways that have a significant population in their surroundings.

A growing demand for RAM can also be derived from current figures provided by business aviation usage as shown in Figure 5-7.

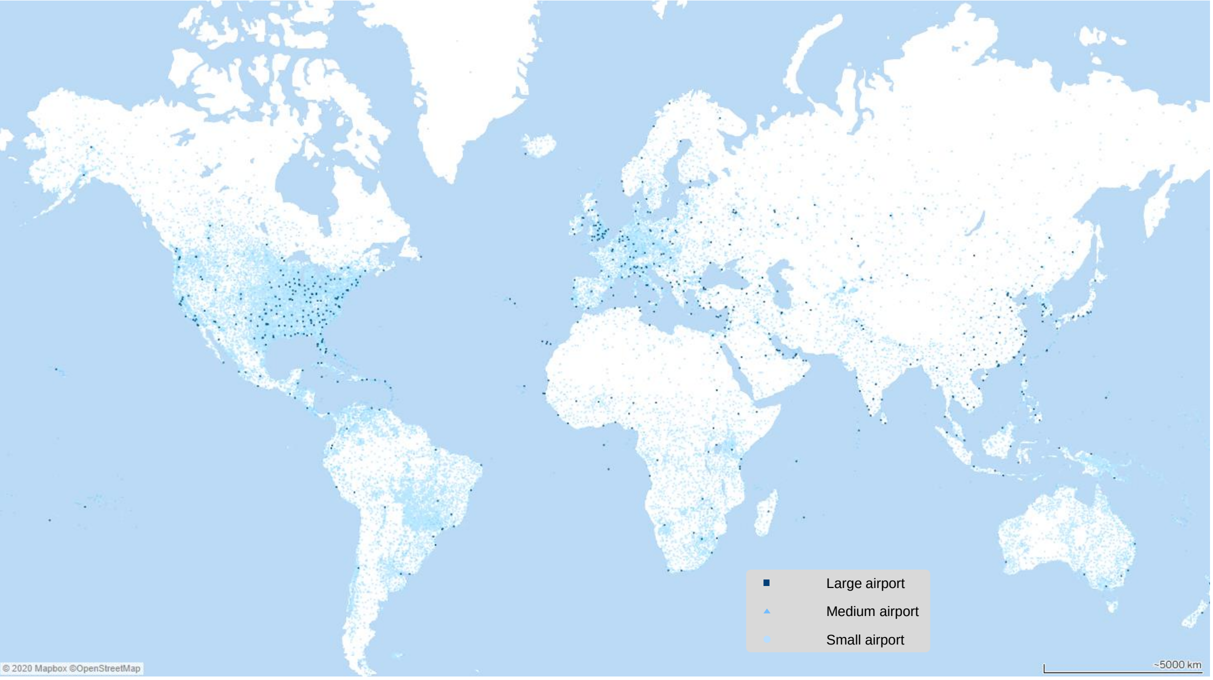

Figure 5-6: Overview of available airports and airfields worldwide[13]

The most frequented business jet connections within Europe are domestic flights in France, Germany and UK. The overall market is growing strongly with a plus of 4.6 % compared to the previous year. A strong growth is also expected for the corresponding US-market.

Not neglecting the fact that the expenditure for a trip with a business jet – that can easily sum-up to a couple of thousand Euros per flight hour – is out of reach for most European travellers, an interesting travel segment for ELICA might be business trips, as a higher willingness to pay for time savings can be identified.[15]

Specific data is again available for Germany. In 2017, between 110 to 187.5 million business trips originated in Germany, as estimated by two different travel associations. More than 50 billion € were spent for those trips, about half of this money was spent on transport. Three quarter of the trips were done by private or company car, reflecting the insufficient transport network offered by German train and aircraft operators. Additionally, train and airplane

[15] German travel association (DRV) - GfK Mobility monitor business trip questionnaire 2018: Online-poll of private households with 1,500 participants in 2017; German association for travel management (VDR) - Business trip analysis 2019: Interviews with 800 business travellers in 2018

connections are regarded as more stressful as travellers are fear delays or cancellations. Such fears can be countered with a point-to-point thin-haul air service as opened-up by concepts like ELICA or the Silent Air Taxi that is currently being developed by Aachen-based e.SAT.[16] The Silent Air Taxi is a small, piloted four seater aircraft to address the market of RAM as analysed by Sun and Kreimeier. e.SAT is focussing on business customers and assumes that silence is a key-enabler for that market, explaining why a huge technical effort is done to bring down noise emissions of the aircraft.

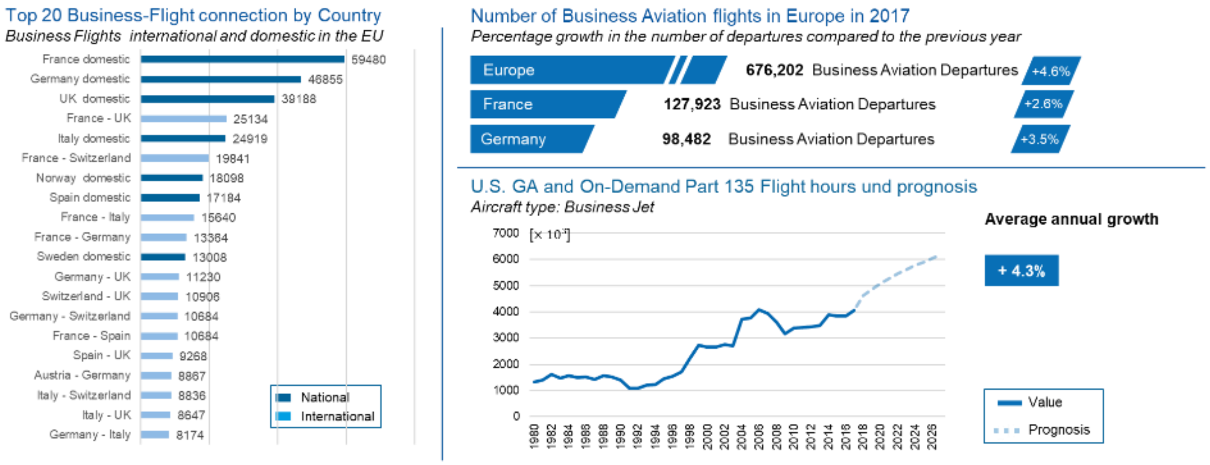

Figure 5-7: KPIs for business aviation[17] [18]

In summary, RAM is key to realise the goal of the European Commission to bring down the door-to-door travel time within the EU to less than four hours for the vast majority of citizens. To achieve this, affordable commuter aircraft of different passenger capacity are needed that can take advantage of existing airfield infrastructure and address routes from 100 to 500 km of length. To compensate initially higher transport cost, one lead customer group might be business travellers that have a higher willingness to pay. Besides scholars also economic entities such as German e.SAT GmbH have realised the potential of RAM and are focussing efforts to develop specialised aircraft to serve this market.

5.2 New business segment thin-haul air cargo

Air cargo volume has grown significantly in the last years and is expected to grow even stronger within the next two decades. In the baseline scenario calculated by Boeing, an annual growth rate of 4.2 % is expected within the next 20 years. Strongest markets in terms of growth rates are forecasted to be domestic china (6.3 %), Intra-East Asia (5.8 %) and East Asia to both North America and Europe (both 4.7 %).

Besides growing cargo volumes due to prospering world economics which is favouring air transport, e-commerce is a strong driver for growth. Most important markets are the US and China. Especially Amazon is setting new standards in terms of customer expectations regarding delivery time and product diversity. To realise this, rising volumes of e-commerce goods are – at least partly – transported via air (cf. Figure 5-8).[19]

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16 Introduction to the Silent Air Taxi: https://e-sat.de/en/silent-air-taxi/

17 EBAA Economic Report 2018: https://www.ebaa.org/app/uploads/2018/01/EBAA-Economic-report-2017_compressed.pdf

18 2018 Annual Report of GAMA: https://gama.aero/documents/2018-annual-report-v2/

19 Boeing World Air Cargo Forecast 2018-2037: https://www.boeing.com/commercial/market/cargo-forecast/#/downloads

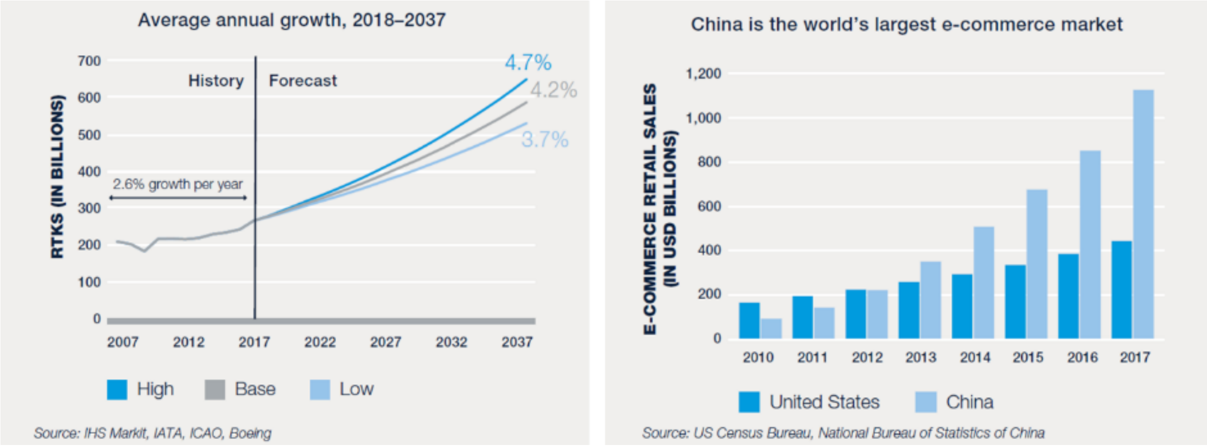

Figure 5-8: Left: Air cargo growth forecast, 2017 to 2037; right: e-commerce sales, 2010 to 2017[19]

Another important driver for air cargo growth is the flowering international express air cargo, which increased from a relative share of the overall air cargo market of 4.1 % in 1992 to 17.1 % in 2017 (cf. Figure 5-9). To handle this amount of time-priority cargo, a growing number of thin-haul aircraft are used to reduce the delivery time further.

Figure 5-9: Left: express share of international cargo, 1992 to 2017; right: forecasted freighter demand in 2037[19]

To satisfy the growing market demand to air cargo and to replace old aircraft, a strong increase of air freighters is forecasted by Boeing. They expect 2,650 freighters to be delivered in the next 20 years, of which 980 will be new production freighters, valued at 280 billion US-Dollars. The remaining share will be filled with freighter conversions from old passenger aircraft.

The number of freighter aircraft with a MTOM of below 40 t are forecasted to rise by 83 % between 2017 and 2037, which is partly addressing the market for ELICA.

A new major player within air cargo is Amazon. Its Prime Air fleet – operating aircraft since 2016 – is growing to 70 aircraft until 2021, most of them leased Boeing 737 or 767 freighter aircraft almost exclusively operated in the US. In the US in 2019, every second Amazon packet is (partly) transported by air freighters. A strong increase from only 10 % in 2017.

The European Amazon air freight market is under development. Focus airports are Cologne/Bonn and Leipzig/Halle. Soon, a 24-hours delivery shall be available for Amazon Prime customers in selected regions. To realise this, a reliable and flexible air freighter fleet is needed. Currently, Amazon Air (what is the official name) is testing also smaller aircraft types, such as ATR 72 (payload of 7 to 8 t or approx. 72 PAX) or Saab 340 (payload of about 4.4 t or approx. 33-37 PAX) operated by Polish SprintAir. First months of operation show that volume of the cargo bay is more important than payload. Amazon Air is operating during daytimes – opposite to established air cargo operators such as UPS or FedEx that run their business mostly during night times – and is cooperating with DHL.[20]

FedEx is moreover an anchor customer for the newly developed Cessna SkyCourier and has ordered already 50 aircraft and indicated to purchase fifty more. The SkyCourier shall replace the Cessna Caravan aircraft fleet operated by FedEx in the US. [21]

DHL has committed to reduce its CO_2-emissions to zero by 2050. A hybrid or fully electric cargo aircraft would help to reach this goal, as DHL is one of the big five air cargo operators worldwide.[22]

Summarising, air cargo is expected to grow strongly, especially to handle e-commerce and express freight. To further reduce delivery times smaller aircraft are used to enable air cargo on thin-haul routes. Moreover, first operators have announced to reduce their CO_2-emissions and therefore will increase the demand for environmentally friendly air freighters. Those arguments support the development of an electro-hybrid 19-seater commuter aircraft such as ELICA and can be regarded as a strong upside-potential for an operator business case.

5.3 Technical upside potential for cost reduction due to electrification

Hybridisation offers a direct cost saving potential for aircraft that is presented in the following section. Three main areas of action can be identified that influence the business case of ELICA:

1. Reduced energy cost of electricity compared to kerosene
2. Reduced maintenance and part replacement cost for the electric power train
3. Electrification opens the design space, so that energetic more efficient aircraft can be built

The first aspect describes the difference in purchasing cost of both energy forms. To compare them equally the actual usable energy per USD must be considered. With data from an example airport in Germany which denotes around 0.95 €/liter without taxes and fees and data from Verivox online portal with denotes an electricity price of 0.22 €/kWh for business applications the price for one kWh of useful energy can be calculated. The result is that flight energy from kerosene is 50 % more expensive than flight energy from electric sources.

Another important aspect regarding energy usage is the characteristic of electric motors to be independent from outside air pressure. In contrast to turboprop engines which provide less power at higher flight levels. Those advantages favour the electric powertrain to be used at high altitudes which allow for more efficient cruise in less dense air and therefore lower the mission energy requirements.

[20] Multiple online news sources: https://www.businessinsider.de/wirtschaft/amazon-das-steck-hinter-den-flugzeugen-von-prime-air/; https://www.welt.de/wirtschaft/plus205373385/Amazon-will-mehr-selbst-liefern-und-bringt-DHL-in-Bredouille.html; https://www.airliners.de/amazon-europa/50075; https://www.wiwo.de/unternehmen/dienstleister/expansion-in-den-himmel-amazons-heimlicher-aufstieg-zum-airline-riesen/23191794.html

[21] SkyCourier portrait: https://cessna.txtav.com/en/turboprop/skycourier

[22] DHL emission goals: https://www.dpdhl.com/en/sustainability/environment-and-solutions.html

Table 3: Energy cost calculation for different sources

Parameter	JET A-1		Electricity	
Price Jet A	0,95[23]	€/l		
Density Jet A	0.81	kg/l		
Price / Mass	1.17	€/kg		
Energy density	12.03[24]	kWh/kg		
Price per kWh energy source	0.10	€/kWh	0.22[25]	€/kWh
Efficiency powertrain	26%[26]	Efficiency	90%[27]	Efficiency
Price per kWh usable energy	0.37	€/kWh	0.24	€/kWh

The second aspect is maintenance and part replacement cost. In general, electric powertrains have less parts and require less maintenance than their fossil fuel counter parts. Especially the thermal stress is less severe than it is for turbine engines which gain their efficiency by high turbine temperatures. The fluids in electric powertrains do not have to be replaced after certain intervals and the same is true for a lot of other parts.

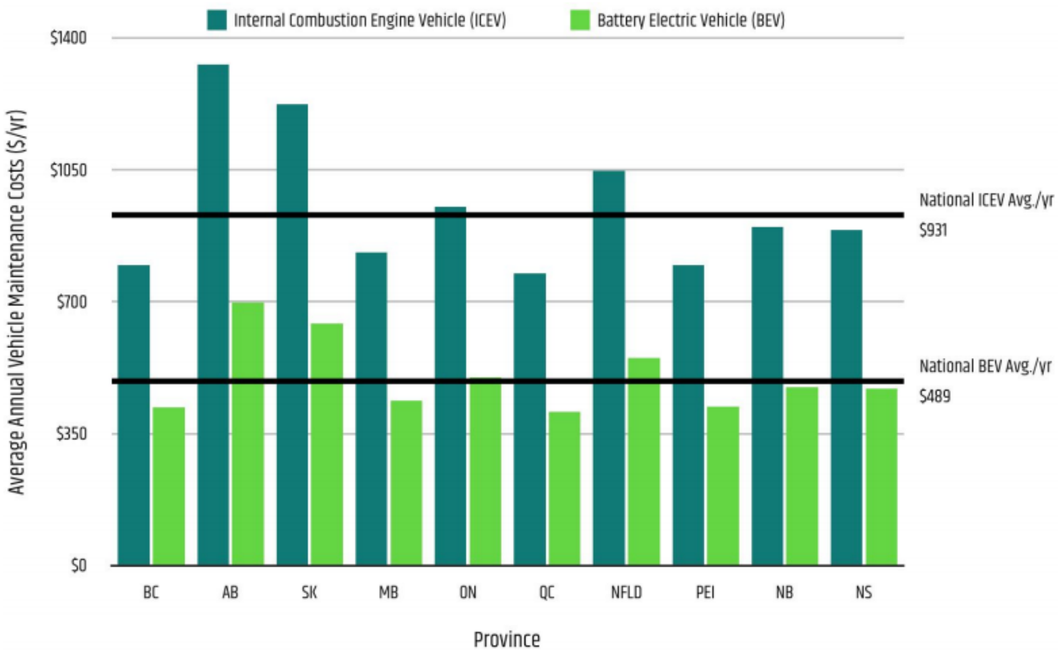

Figure 5-10: Comparison of vehicle maintenance cost

23 http://www.flugplatz-hassfurt.de/navid.14/flugbetriebsstoffe.htm - 31.03.2020 Jet-A1 excl. energy tax= 1.311*1/1.19=1.11€ w/o taxes

24 Aviation Fuels Technical Review | Chevron Products Company 2004

25 Business prices – Verivox; https://www.verivox.de/gewerbe/ - 31.03.2020

26 AviationWeek Jan. 2008 - Gas Turbine Engines TPE331-12UHR – Calculated from SFC 0.522 lb/hp/h

27 Georgi Atanasov et al. Electric commuter transport concept enabled by combustion engine range extender

However, there is no literature regarding maintenance cost for electric aircraft, but as a comparison the car industry can be used. In Figure 5-10 the average annual vehicle maintenance cost for an electric vehicle and an internal combustion engine vehicle are displayed for different provinces in Canada. As a result, the maintenance cost for electric vehicles is about 47 % lower than for the fossil fuel powered version. This is supported by several electric aircraft companies that expect maintenance cost to be reduce. For example, the 2,000-hour overhaul on the Pipistrel Alpha Electro electric Motor is only 500 € plus 12 hours of labour.[28]

The third aspect is due to the fact that the change in propulsion technology will lead to new aircraft design paradigms, and the impact on aircraft design can be similar to the introduction of jet propulsion technology in the middle of the last century. For the SCEPTOR concept based on a Tecnam P2006T, NASA estimates that the energy consumption can be 4.8 times less at the selected cruise point when compared to the original aircraft.[29]

In summary there are several potentials for cost saving due to electrification. However, the greater part depends on how regulatory requirements and the oil price develop. If the oil price rises again to the levels that occurred in 2008 and the CO_2 price increases significantly, there will be a major cost advantage for electric flying.

5.4 Regulative upside potential for cost reduction due to electrification

In the current public debate a lot of attention has been on the negative environmental impact of aviation as it accounts for 1.5 to 2 % of anthropogenic CO_2 emissions including land use change (LUC) as can be seen in Figure 5-11.[30] Flying is often seen as a non-essential amusement. Regulations have already been put in place to incentivise the aviation industry to cut down on emissions. Airports charge every flight specifically for nitrous oxide (NOx) emissions for example and through the European Emission Trading System (EU-ETS) a ton of CO_2 emission cost about 25 € today.[31]

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28 Aircraft Information Pipistrel Alpha Electro; https://www.pipistrel-usa.com/wp-content/uploads/2018/03/Pipistrel-Alpha-ELECTRO-Information-Pack.pdf

29 Borer, Nicholas et al. Design and Performance of the NASA SCEPTOR Distributed Electric Propulsion Flight Demonstrator

30 https://www.iata.org/contentassets/8d19e716636a47c184e7221c77563c93/technology20roadmap20to20205020no20foreword.pdf

31 https://markets.businessinsider.com/commodities/co2-european-emission-allowances/euro

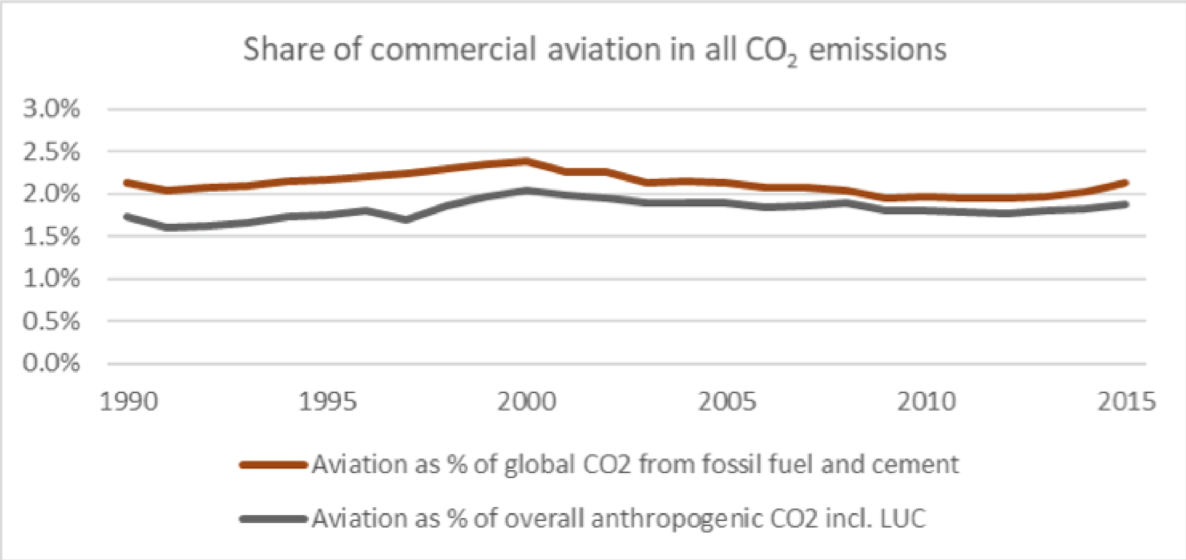

Figure 5-11: Commercial aviation CO_2 emissions compared to overall anthropogenic CO_2 emissions. © IATA

The largest potential to save CO_2 and therefore also to reduce cost levied on emissions is in the regional segment. Figure 5-12 shows that the shorter the flight distance the greater the carbon intensity. On regional routes of 500 km or less carbon intensity stood at roughly 155 g of CO_2 per Revenue Passenger Kilometre (RPK) in 2018.[32] It is assumed that ELICA could save 172 kg of CO_2 in a pressurised and 196 kg of CO_2 in an unpressurised configuration per mission (cf. Table 7). This would translate into CO_2 related cost savings of 4.30 € or 4.89 € per mission respectively. When looking at how government policy might evolve in the future though these cost savings increase significantly. The 'Fridays for Future' student climate protest has demanded a price of 180 €/t CO_2. At this price level CO_2 related cost savings would increase to 30.97 € or 35.22 € per mission. Assuming 969 yearly missions for ELICA would save an airline 30,000 € or 34,100 € p.a. per aircraft. The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) aims to stabilise CO_2 emissions from international aviation at 2020 levels. It will be put in action in 2021 and is sure to increase the price of carbon emissions already.[33]

32 https://theicct.org/sites/default/files/publications/ICCT_CO2-commercl-aviation-2018_20190918.pdf

33 https://ec.europa.eu/clima/policies/transport/aviation_en

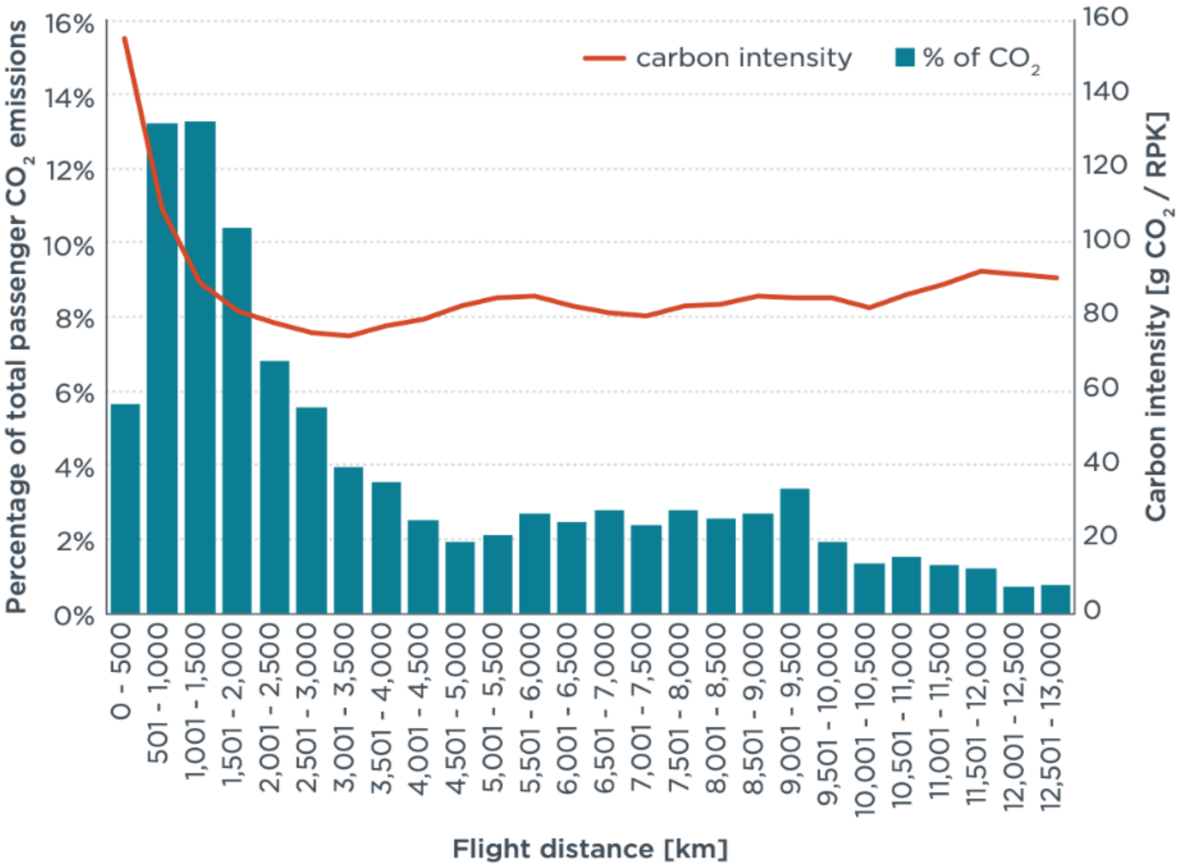

Figure 5-12: Share of passenger CO_2 emissions and carbon intensity in 2018, by stage length. © ICCT

Carbon pricing is not the only way by which emission reductions can be recompensated, however. In Norway proposals already exist to provide tax exemptions or to reduce aviation charges.[34] If all these measures work hand in hand a very capable package would be developed that could change the operating economics of electrified aircraft significantly. The International Council on Clean Transportation (ICCT) believes that measures to reduce emissions are gaining momentum but believes that more work is needed especially regarding regulation. Ursula von der Leyen, President of the European Commission presented the European Green Deal in December 2019 setting the ambitious goal of being climate neutral by 2050.[35] With politicians like her setting new goals it is very likely that more regulation is on its way that will push operators to lower their emissions.

5.5 Aircraft noise

Asides from typical emissions such as CO_2, NOx or H_2O, typically labelled as greenhouse gases, there are other types of emissions with a significant share in the ecological footprint of aviation. One of these is noise pollution, which is often overlooked for effects on a global scale but very important for residents close to airports of all sizes. Noise pollution has a direct impact on risks for airport operators, regarding limitation on hours of operations etc. and on the cost structure of the airport. Those increased cost, for example to shield residents from certain noise levels are passed on to aircraft operators. To reflect the different impacts of different

34 https://kommunikasjon.ntb.no/data/attachments/00315/9dead1eb-37e9-4fad-8dd7-9176de9c3011.pdf

35 https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/actions-being-taken-eu_en

aircraft types, those fees are based on actual measured or certified noise levels. Hence, there is a direct incentive for airport and aircraft operators to reduce noise pollution all around.

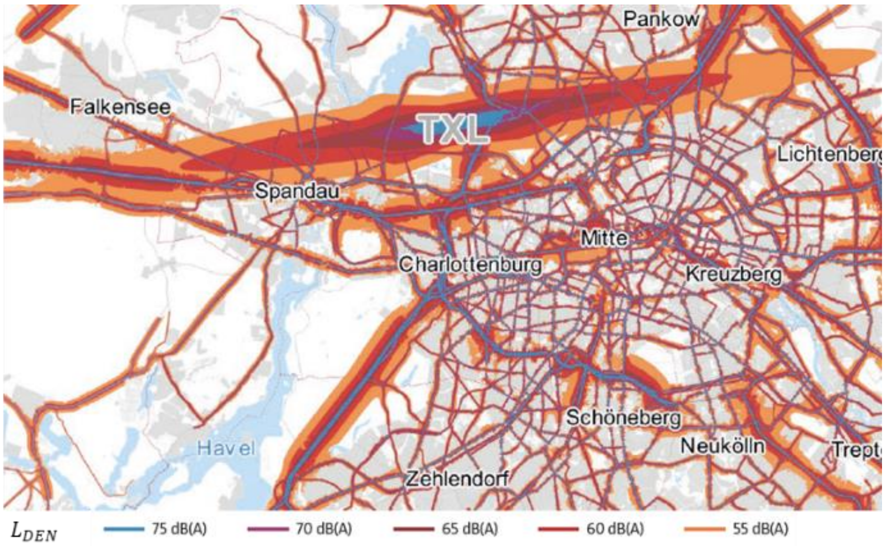

Figure 5-13: Noise pollution levels around Berlins international airport Tegel, Germany[36]

Scientific literature provides a proof, that it is not a question of whether noise has a health impact, but how big this impact is. The World Health Organisation (WHO) list in its 2018 Environmental Noise-Guidelines for the European Region[37] the following main health impacts of noise pollution:

- Cardiovascular diseases
- Feelings of displeasure, restlessness and annoyance
- Insomnia
- Cognitive impairment

Noise originates from small differing levels of air pressure, which are transmitted as waves through the air. The sound pressure is measured as the logarithmic sound pressure level dB(A). To build a basis for mitigating noise most countries detailed plans on how to and where noise levels must be monitored. To provide a reference value for the overall noise doses throughout a day or during night, weighted averages were introduced to consider both peak noise and average noise background levels for the entire day (L_{DAN}) and for night-time (L_{Night}).

Figure 5-13 shows the equivalent sound pressure levels originating from all transport sources around Berlins Tegel airport. It is clear, that although highways generate a significant noise pollution in their immediate surrounding, the airport generates the largest footprint with levels as high as 65 dB(A) present across large urban areas.

In total more than 34,000 people in Germany are affected by aircraft noise L_DEN > 65 dB(A) and over 815,000 by L_DEN > 55 dB(A). At an exposure level of 55 dB(A) 35% of the population already feel considerably disturbed (cf. Figure 5-14).

36 Report on aircraft noise airport Berlin Brandenburg: https://publications.berlin-airport.de/ber-aktuell-04-2017/58050004

37 WHO report on noise: www.euro.who.int/__data/assets/pdf_file/0008/383921/noise-guidelines-eng.pdf?ua=1

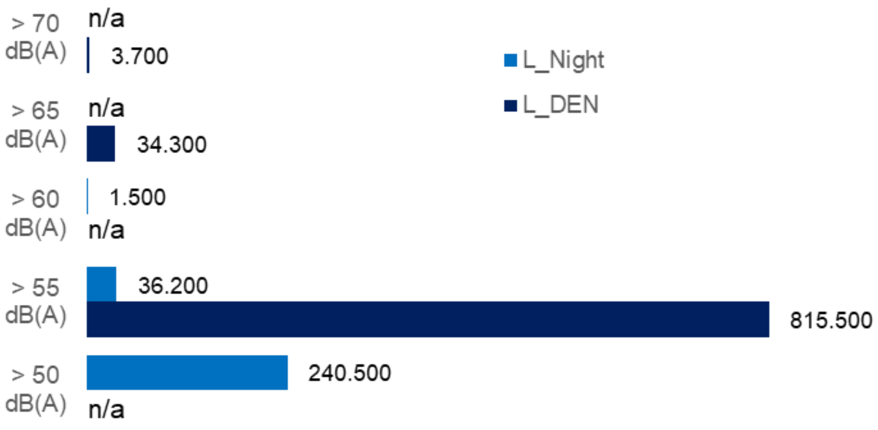

Figure 5-14: Number of people affected by aircraft noise in Germany[38]

To reduce the impact of aviation noise pollution Germany has defined requirements to monitor the levels and worked out detailed plans how the impact can be reduced. How extensively this work must be carried out depends on the airport category, derived from the annual number of commercial take-offs and landings:

- High level > 50,000 flights p.a.
- Medium level > 25,000 flight p.a.
- Low level >15,000 flight p.a.

As there is a forecasted growth in air traffic of CS-23 aircraft, more airports will have to take stricter measures to prevent a growing number of citizens affected by aircraft noise. Therefore, those aircrafts must produce less noise than current designs, otherwise operation will not be possible.

For the CS-23 category noise measurement is conducted via the procedures detailed in ICAO Annex 16: Aircraft Noise – Chapter 10: ‘Propeller-driven aeroplanes not exceeding 8,618 kg maximum certificated take-off mass’. The procedure is displayed in Figure 5-15. In short, a full power take-off at MTOM is conducted with a microphone placed 2.5 km away from the point of break release. After getting airborne the aircraft climbs with take-off power at the best rate

38 Report on aircraft noise 2017, UBA: https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2017-07-17_texte_56-2017_fluglaermbericht_v2.pdf

of climb speed. For all aircrafts that are certified via this method high initial climb rates are beneficial for a favourable noise classification.

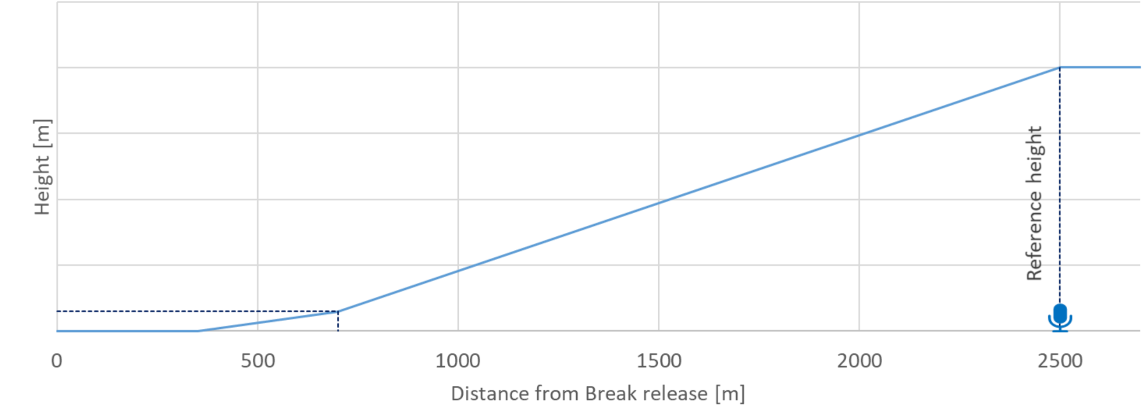

Figure 5-15: Noise certification reference procedures ICAO Annex 16 Volume 1 Chapter 10

The maximum allowed limits for the measured sound pressure levels depend on the aircrafts certified MTOM. Single-engine aircrafts up to a MTOM of 570 kg are limited at 70 dB(A). Between 570 kg to 1,500 kg it is defined as a logarithmic curve until it tops out at 85 dB(A). For multi engine aircraft the limit starts at 76 dB(A) and reaches 88 dB(A) for an MTOM of 1,400 kg or more. In Germany there is another limit defined in the Airfield Noise Protection Act, which is around 7 dB(A) to 8 dB(A) lower than single engine limits. In Figure 5-16 those dependencies are displayed. Additionally, there are several certified sound pressure levels filled in for a wide range of CS-23 aircraft.

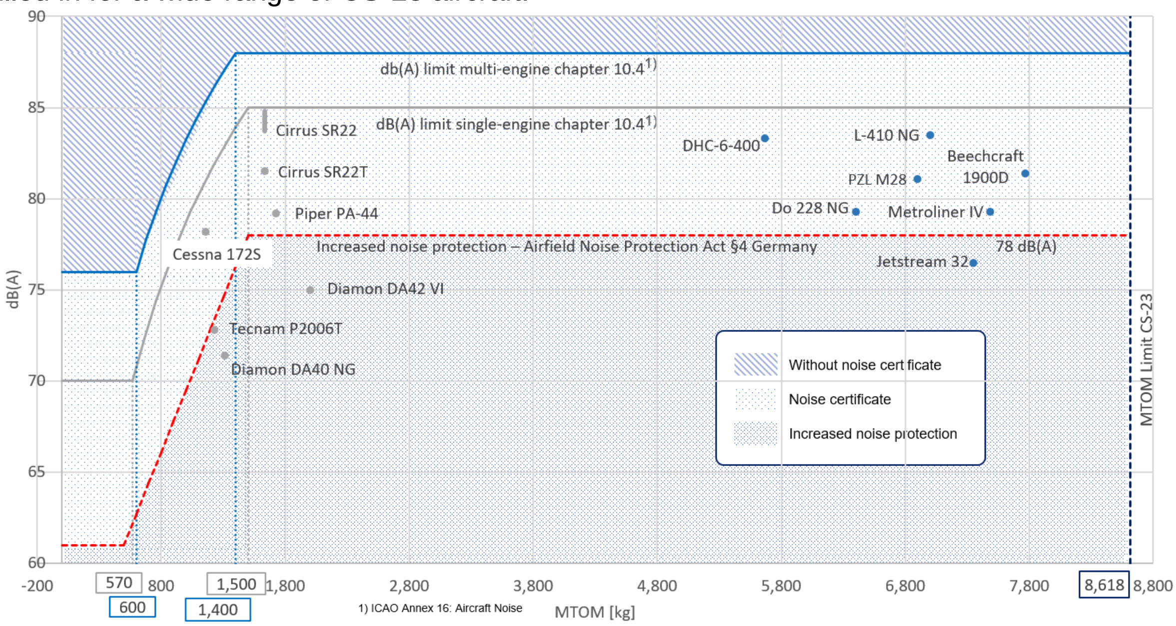

Figure 5-16: Measured ground noise for a range of small aircraft[39]

It is apparent, that small aircraft with modern turbo charged engines achieve the best values. For example, the DA40 NG with around 72 dB(A). However, even older and much heavier commuter category aircraft can achieve very good results, if they are equipped with modern, often purposely build propeller blades. The reason for later recertification of new propellers is that noise is both a big factor in terms of passenger comfort and in airport fees.

39 Air s.Pace desk research

A study of 18 airports in Germany revealed that landing fees increase by an average of 26 % if the increased noise protection cannot be guaranteed. If no noise certification data sheet is submitted at all, the fees increase by additional 48 %.[39] It is possible that those numbers increase further in the future since there is increasing attention to noise pollution.

In summary, the ELICA aircraft design process should consider noise emissions to develop and build a fully environmentally friendly aircraft.

5.6 Aircraft interior

For the flying public the aircraft is mainly visible through the interior. It is what defines the experience for them and for most of them the main thing that they will take away. However not just the flying public will be using the interior of the aircraft but also people from a lot of other professions. Historically speaking a 19-seater also carries cargo, patients in medical emergencies or military operators. This means that several different use cases are possible and the interior needs to be henceforth adapted. The more flexible a possible 19-seater in 2050 is the better. This comes and goes with the aircraft’s cabin. Both the flexibility before entering service and after entering service should be taken into account. This means the flexibility when ordering the aircraft and how to adapt it when it is already in flying service.

Current 19-seaters already offer great degrees of flexibility; however, their cabins have been designed with either passenger or cargo transport as their primary objective. This means that flexibility is always limited and leaning to one side or the other. In order to achieve maximum flexibility an approach that could equally cater passenger and cargo transport should be pursued if economically viable.

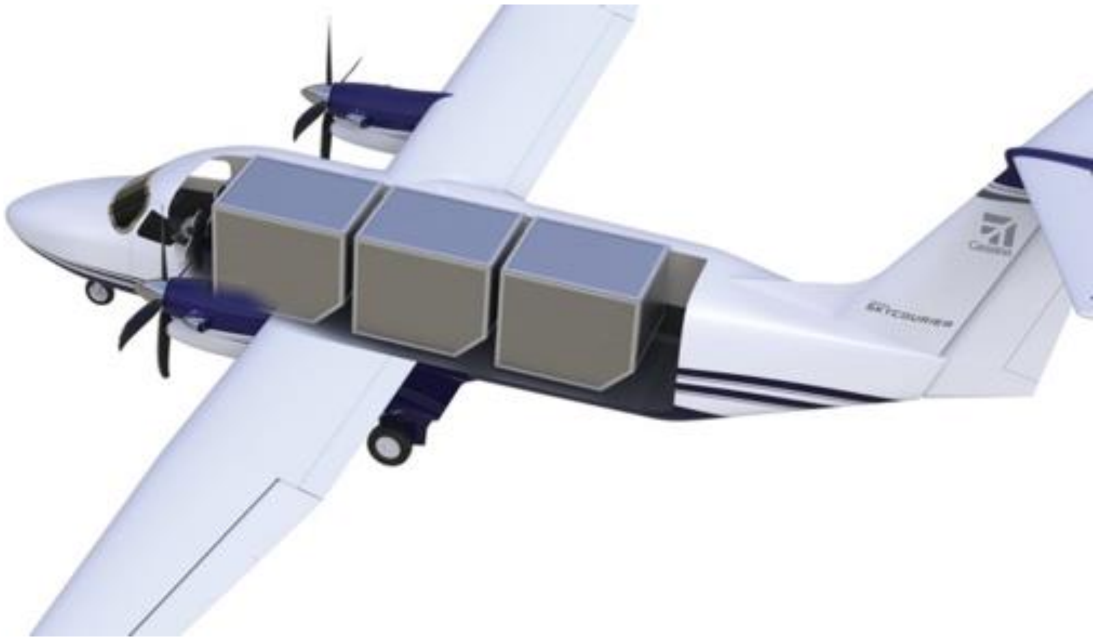

Figure 5-17: Cessna SkyCourier capable of carrying 3 LD3 containers. © Textron Aviation

Adding to the obvious scenarios of passenger or cargo transport or the combination of both at the same time, medical evacuation (MEDEVAC) or surveillance operations of any kind are two other scenarios that aircraft in the 19-seater segment are frequently used for. A modular cabin that can be changed within little time would increase versatility for the operator while in service. Different key-features of the cabin will be explored.

The aircraft cross-section has a large influence on the passenger comfort. The most obvious example is the Beechcraft 1900D as the main feature of this derivative of the base B1900 model was the enlarged cross-section in order for passengers to be able to stand up straight. Another deciding factor would be whether or not to store industry standard LD3 containers. Utilising widely used containers increases efficiency for prospective customers as the turnaround time of the aircraft can be greatly decreased. If pressurisation is needed, then their accommodation would increase the size of the cross-section as a cylindrical cross-section is required leading in turn to higher drag or higher fuel burn.

A modular cabin would be used to give great versatility to operators after entering service. The cabin would therefore have to be developed in a manner that reinforcements for passenger seats are placed so that they can be used in a MEDEVAC scenario as well and no additional reinforcements are needed. It should be possible to change equipment within a short timeframe in order for operators to be able to adapt quickly to their needs. An example is Fiji Airlines who have during the current COVID-19 crisis reconfigured their Twin Otter aircraft with a stretcher for medical transports.[40]

Figure 5-18: different Twin Otter cabin configurations. © Viking Air & Fiji Airways

Taking the example of the newly developed Cessna SkyCourier a large cargo door is first and foremost needed for loading and unloading cargo. However other features would be needed in order for it to achieve its full potential. These would be a flat un-angled floor, good accessibility of the cargo door from the outside (empennage design comes into play) and a cross-section that would allow to store industry standard LD3 containers. A cargo door would also be of great help to a modular cabin to cut down on the duration to swap out cabin elements by increasing accessibility to the cabin.

For a commercial passenger operation, the obvious choice would be to have a pressurised cabin, however a non-pressurised cabin could be of use in military environments. Since surveillance missions by 19-seaters usually take place below 3,000 m and as externally mounted sensors are constantly evolving their integration is eased by a great deal in a non-pressurised cabin. Having a non-pressurised cabin reduces complexity and frees up weight for other systems such as externally mounted sensors.

40 https://twitter.com/FijiAirways/status/1244393300632584193

When designing the cabin, the two key decisions on the pressurisation options and the cross-section are of great importance due to their profound impact on the possible use cases for the aircraft. Their up- and downsides should therefore be thoroughly examined before taking a decision. The greatest possible flexibility should be ensured as it is not known yet what other use cases might develop in the future so the aircraft should be prepared as good as possible. An example of that would be the cargo door which could be very easily be replaced by a rolling door for parachuting. It would be a by-product of the cargo door that could be added without no major added complexity. It is clear that a modular cabin should be available in any case in order to maximise the versatility, since there are no major drawbacks of having one. In a future 19-seater such design elements should be identified that have already proven in the past to allow room for later development in a flexible manner.

5.7 Case study Scotland

ELICA is not the very first project exploring the electrification of commercial aviation and lately efforts around have been taking-off. According to consulting firm Roland Berger the number of electrically propelled aircraft developments has grown by around 30% in 2019 to 215.[41] It is therefore interesting to look at a few promising projects that have already been initiated which look very promising and take example. One of them is the project Fresson in Scotland, United Kingdom (UK) which is a government funded cooperation between an airline and the aircraft manufacturing industry. The project takes a very modest approach at electrification by using parts available today and is exploiting favourable geography. Due to that it is very realistic that the project will actually be successful and could very well be a steppingstone for the whole industry.

Scottish airline Loganair operates the world's shortest scheduled flights between the Orkney islands. The longest of these flights is 15 minutes long and flights are operated by the Britten-Norman (B-N) Islander aircraft. Having secured 9 million GBP of funding[42] (10.5 million €) in November 2019, a number of companies will work together to convert the B-N Islander into a hybrid-powered aircraft. The projected total cost stands at 18.6 million GBP (21.7 million €). The aim is to have 60 minutes endurance with 30 minutes reserve in pure electric flight. Afterwards a turbine-powered generator mounted in the fuselage will step in as a range extender.[43] The current B-N Islander type used by Loganair (BN-2B-26) has an economical cruise speed of 233 km/h True Air Speed (TAS).[44] This translates into a range of 350 km of purely electric flight. When looking at Figure 5-19 depicting all available airfields in Scotland, it can be seen that this range already opens a lot of possibilities. The average distance between Scottish airports stands at 235.40 km. Not just the Orkney islands (circled in red) but also a large but of most other the other 37 Scottish airports can be connected by purely electric flight.

Serving Scotland electrified is not just possible from a range perspective but also from a runway perspective. Airports on the Orkney islands are amongst the Scottish airports with the shortest runways (the shortest runway length is 527 m).[45] Using the distribution of runway lengths in Figure 5-20 it can be said that if an aircraft can land on the Orkney islands it can land almost anywhere else in Scotland as most other airports have longer runways.

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41 https://www.rolandberger.com/en/Point-of-View/Electric-propulsion-is-finally-on-the-map.html

42 https://my.sharpcloud.com/html/#/story/9517f066-5610-4308-bf0b-4be1eace4bd4/element/4e05ba59-e58c-4607-88a4-fecb866c15bf

43 https://www.avweb.com/aviation-news/u-k-company-building-short-hop-electric-airliner/

44 http://britten-norman.com/products/islander/

45 https://www.aurora.nats.co.uk/htmlAIP/Publications/2020-03-26-AIRAC/graphics/138416.pdf

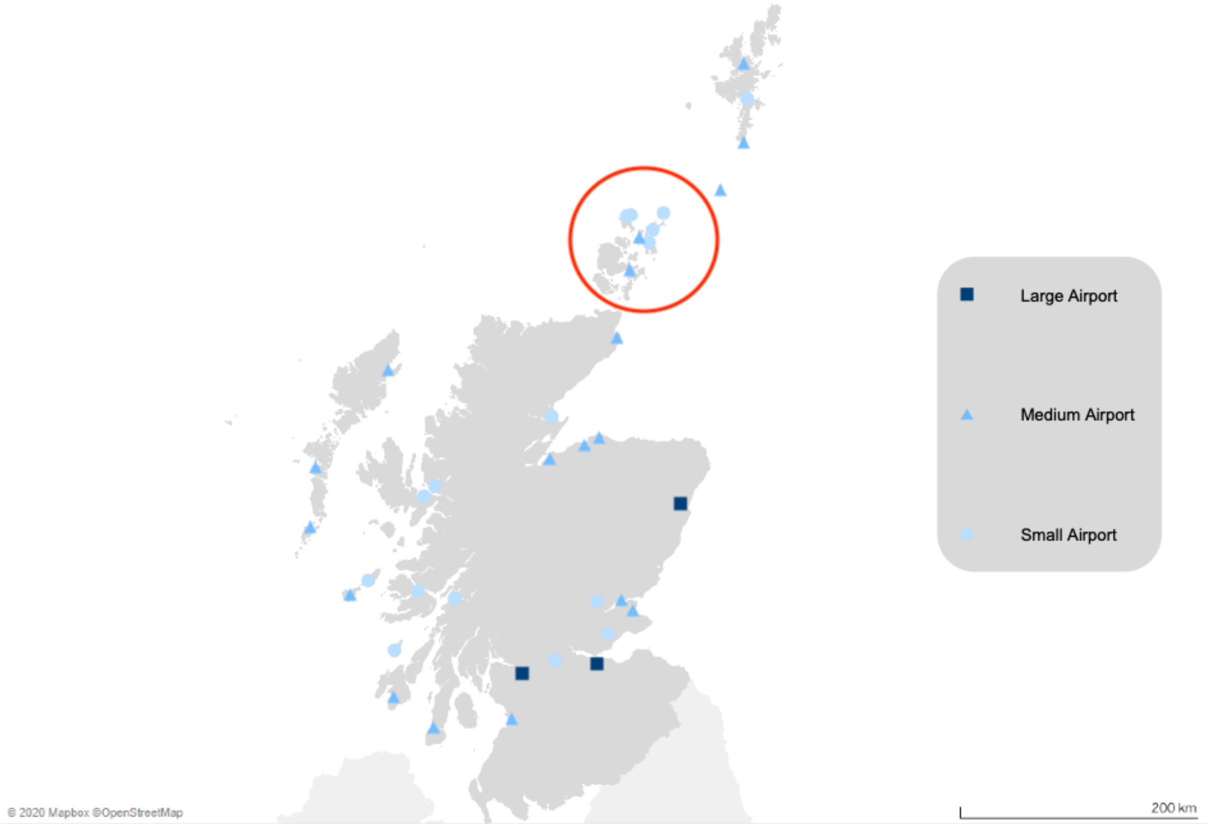

Figure 5-19: Available small, medium and large airports in Scotland. Red circle: Orkney islands

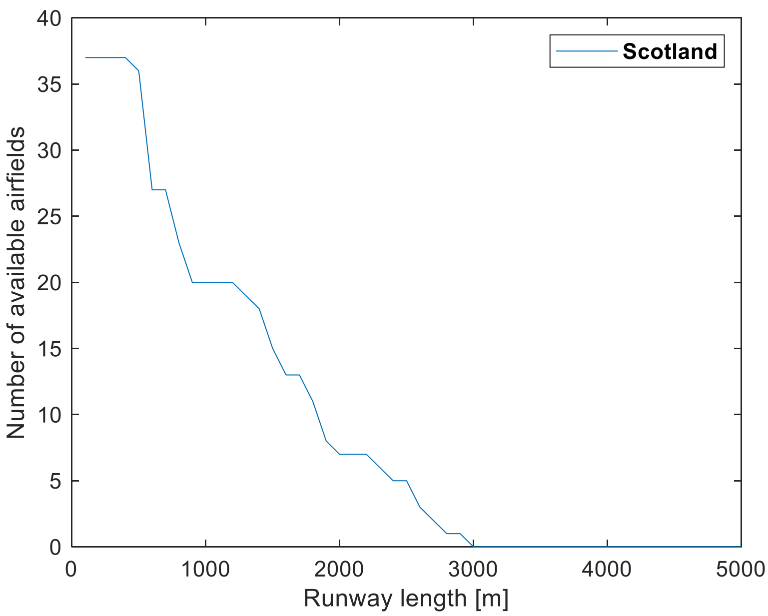

Figure 5-20: Number of available airfields over runway length for Scotland

Two large aviation power houses are involved in the project which are Cranfield Aerospace Solutions (CAeS) with the university itself doing some key research and Rolls-Royce (supplying the power management system). Working with them are B-N as original equipment manufacturer (OEM) to provide the aircraft and data/design support, the Dennis Ferranti Group for the electric motors, Delta Motorsports for the battery packs and the University of Warwick performing battery testing and characterisation. CAeS as a Design Organisation Approval (DOA) holder will lead the project.

According to FlightGlobal[46] the Lycoming engines of the B-N Islander are expected be replaced by a series-hybrid design based on the M250 helicopter turboshaft. As over 40 different variants exist of the M250 with wide ranges of power outputs it is very difficult to say how much power the generators will deliver. Loganair currently uses a BN-2B-26[47] with an Avco Lycoming O-540-E4C5[48] with 193.8 kW (260 hp). No further details can be found as to how the aircraft should be equipped only that AvWeb states that motors, batteries and controls will be 'off-the-shelf'. Their approach is to 'keep it simple'.[49]

The project should last two and a half years, with maiden flight of a first electric aircraft demonstrator planned for mid 2022, followed by Entry into Service (EIS) in 2023.[43] Afterwards a modification kit will be certified through EASA to obtain a Supplemental Type Certificate (STC) in order that current operators of more than 400 B-N Islanders can easily get the same modification. Later another two phases are meant to follow in the long term: In the second phase an existing 19-seater will be modified in a similar fashion and in the last one a new 19-seater is meant to be developed.

Since starting to follow through with Brexit the UK's prime minister has heavily increased research spending to strengthen the UK's position in the future. Project Fresson could be a lighthouse project for the country. However, since the last announcements around project Fresson it has also been announced that the UK's Civil Aviation Authority (CAA) will leave EASA at the end of 2020 meaning that the certification of the modification kit could get more complicated.

It can be concluded that the main aim of the current phase of project Fresson which is the electrification of a B-N Islander is very feasible. The fact that the aircraft will very likely fly in the near future and not be limited to existence on a piece of paper should be a good motivation to others in the industry. When it happens, it would also spread awareness in the public which has been quite wary of flying recently. Even though later phases of the project are a lot more ambitious the project will still be success even if it stops after the first phase.

5.8 Case study Norway

While having looked at a single project that is very promising in Scotland, a plethora of projects aiming to electrify aviation can be seen in Norway. This can be first and foremost attributed to efforts by the Norwegian government, which has put minimising the environmental impact of aviation on its agenda. After being very successful in electrifying cars and ferries, it wants to use its expertise to electrify aviation to connect its sparsely populated country which is connected by many different medium and small sized airports as can be seen in Figure 5-21.

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46 https://www.flightglobal.com/engines/uk-project-to-install-hybrid-electric-power-in-bn-2-islander/135481.article

47 https://www.youtube.com/watch?v=qBph7Ztn4h8

48 https://www.easa.europa.eu/sites/default/files/dfu/EASA-TCDS-A.388_BN2_Islander_Series-01-08112011.pdf

49 https://twitter.com/WMGBusiness/status/1197096901243527169/photo/1

Figure 5-21: Available small, medium and large airports in Norway

In order to do that the Norwegian government commissioned its CAA and the state-owned airport operator 'Avinor' which operates a total of 44 Norwegian airports (all but 4 commercial airports) to develop a program for the introduction of electrified aviation.[50] The two organisation handed in a report in March 2020 setting out the strategy for the coming years. In the report the goal has been set that by 2030 the first ordinary domestic scheduled flights be operated with electrified aircraft. Ten years later in 2040 all civil domestic aviation shall be operated with electrified aircraft, reducing greenhouse gas emissions by at least 80% compared with 2020.[34]

In the report an all-encompassing approach is set out ranging from international cooperation, tax exemptions over to investment support. All these measures lead to great momentum in general around electrifying aviation which is also the aim of the Norwegian government. The director of CAA Norway Lars Kobberstad can be quoted: 'It is in Norway's own interest - from the perspective of both climate, district and transport policies - that zero and low-emission aircraft are developed which are capable of operating on the unique Norwegian short-haul network under the prevailing meteorological conditions in the country'.[50] This shows that Norway wants to be a global gateway for the electrification of aviation and since there are several projects which are already ongoing this process is already starting.

The unique Norwegian short-haul network that Mr. Kobberstad is referring to is characterised by the cold Norwegian environment and short runways. Currently the shortest runway served is in Båtsfjord (ENBS/BJF) at 810 m. In the distribution of runway lengths in Figure 5-22 it can be seen that there is a large number of airports in the STOL runway region between ~800 m and ~1,200 m.

50 https://kommunikasjon.ntb.no/pressemelding/norway-a-driving-force-and-arena-for-electrification-of-air-travel?publisherId=17507039&releaseId=17880988

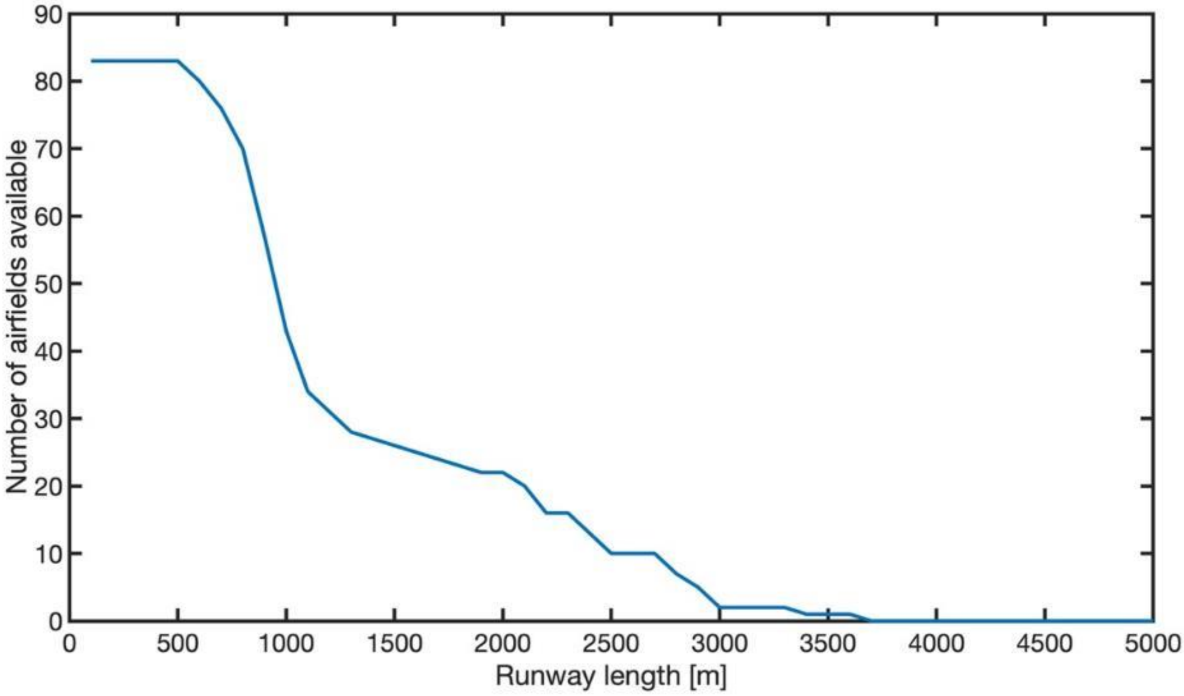

Figure 5-22: number of available airfields over runway length for Norway

As it is stated in the report by Avinor and CAA Norway[51] that a runway length of 800 m can very well be a limitation to aircraft manufacturers it could be an option to develop a separate STOL capable version later on to accommodate the shorter runway airports. Norway depends on aviation to connect its small communities which explains why it is making such great efforts.

Avinor is heavily engaged in pushing the electrification of aviation in Norway forward as it will also be responsible for developing a charging infrastructure across Norway. It can be seen as an advantage that by having this single player a uniform charging system can be developed.

At the moment the only electric aircraft that is actually sold is the Pipistrel Alpha Electro which is why Avinor together with the Norwegian Air Sports Association bought the country's first electric aircraft in June 2018 to fly it at public events to spread awareness around electric flying.[52] To accelerate the use of electrified aircraft and gain experience in their operation it is recommended in the joint report that aircraft like the Pipistrel aircraft in GA used in voluntary activities are exempted from VAT. Further all electric aircraft have already been exempted from landing and charging fees until 2025.[53] It shows a very pragmatic approach as the loss in revenue is conceded. This can be explained by the fact that with current technology it is easiest to electrify light aircraft and later move further up to heavier aircraft which the government or rather government agencies want to support.

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51 Page 51 of report

52 https://www.pipistrel-aircraft.com/the-first-flight-of-an-electric-airplane-in-norway/

53 https://kommunikasjon.ntb.no/pressemelding/norways-first-electric-powered-flight-takes-to-the-skies?publisherId=17507039&releaseId=17575239

An example of that is Norwegian pilot training provider OSM Aviation which has ordered 60 eFlyer 2 aircraft from Bye Aerospace in the USA in April 2019.[54] Bye Aerospace, like many other companies believes that electric aircraft can be operated at a significantly lower hourly cost rate.[55] Apart from the profound environmental impact electric planes would make it is obvious that superior operating economics will help their widespread adoption. OSM Aviation will start the adoption by 2021.[56]

It can be concluded that Norway is on the path to be one of the leading nations in the electrification of aviation. It is already taking centre stage with regulators having initiated work of the Task Force on Zero Emissions Aviation with EASA in February 2020.[57] Every player in the Norwegian travel industry is on their toes to get the momentum going which is exemplified by Berg-Hansen a Norwegian travel agency hosting a conference itself on the electrification of aviation in May 2019.[58] It is clear that there is great motivation in Norway and more and more companies from all over the world will flock to Norway to work together on the electrification of aviation. The latest example is EHang which in March 2020 has obtained its first operational flight permit for long term testing for its EHang 216 passenger autonomous aerial vehicle (AAV) from CAA Norway.[59] Every different part of the industry is working to achieve one common goal.

5.9 Case study Cirrus Aircraft

Cirrus Aircraft[60] demonstrated in 1999 that a market entry into a General Aviation market is possible and can be highly successful. The company was founded in 1984 and introduced a kit-aircraft to the market in 1999. With only 13 units sold, the success was limited. Nevertheless, Cirrus focused on the development of the SR20 (cf. Figure 5-23), a single-piston engine aircraft, which was introduced to the market in 1999.

Figure 5-23: Aircraft developed and produced by Cirrus Aircraft. © Cirrus Aircraft

Market introduction was highly successful, as Cirrus was able to secure a market share within the piston engine market of 10 % within two years and then 23 % from 2002 onwards.

Since then, Cirrus defends this market share and sells as of today about one quarter of all piston engine aircraft worldwide. As shown in Figure 5-24, only two years after the introduction of the Cirrus SR20 an upgraded version (SR22) was introduced, followed by a turbo loaded

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54 https://osmaviation.com/osm-aviation-aims-for-a-green-future/

55 https://www.aerokurier.de/bye-aerospace-elektroflug-kostendaempfer-und-innovationstreiber/

56 https://byeaerospace.com/3715-2/

57 https://www.easa.europa.eu/newsroom-and-events/press-releases/european-industry-and-regulators-unite-provide-roadmap-zero

58 https://www.berg-hansen.no/blogg/berg-hansen-konferansen-derfor-haster-det-med-el-fly/ translated with Google Translator

59 https://www.ehang.com/news/613.html

60 Homepage of Cirrus Aircraft: https://cirrusaircraft.com/aircraft/

version in 2010. Impressive is moreover the sharp market decline due to the financial crisis 2008/2009. Cirrus was able to defend its market share, but overall sales still not reached the level of 2007.

But how did Cirrus manage to break up an existing market with a completely new aircraft? They developed a state-of-the-art aircraft with modern technologies, e.g. by an early introduction of composite materials and an electronic flight instrument system ('glass cockpit'), a high level of passenger comfort in the cabin oriented on automotive standards and several additional safety features, not implemented into any piston aircraft before, e.g. a parachute system or an electronic stability protection system.

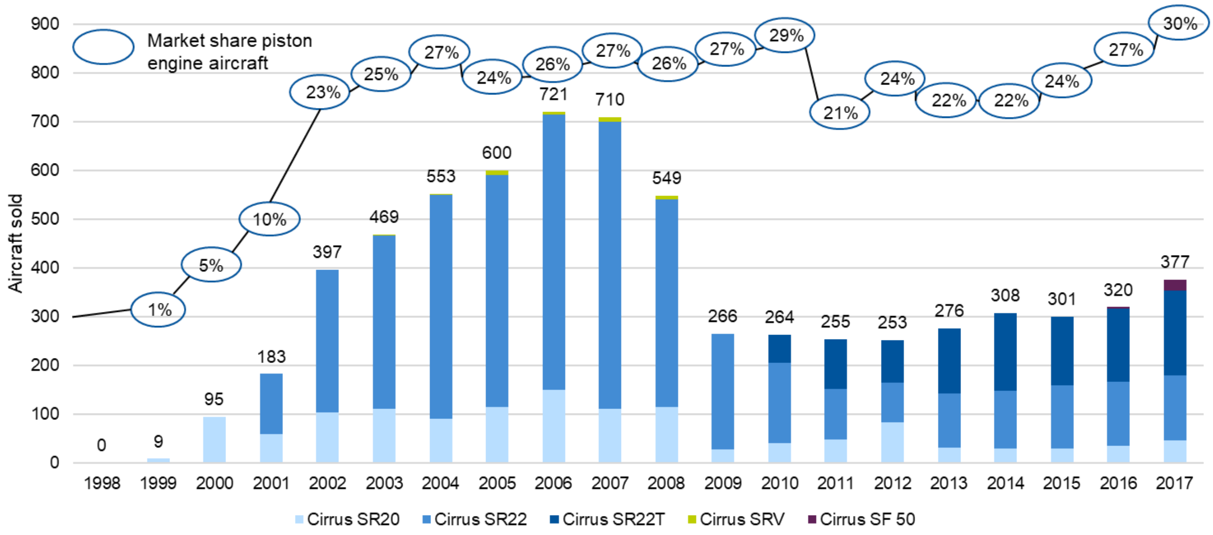

Figure 5-24: Cirrus aircraft sales and market share, worldwide, 1998 to 2017[61]

Figure 5-25 showcases the huge differences between e.g. a Cessna 172 in 2003 and a Cirrus SR22.

Due to the enhanced quality of the aircraft, Cirrus was able to enforce a higher price level in the aircraft market, to increase it continuously (the red dotted line shows the effect of the annual inflation) and to reason higher prices for each of its platform derivates (SR20, SR22, SR22T), as shown in Figure 5-26.

61 2018 Annual Report of GAMA: https://gama.aero/documents/2018-annual-report-v2/

Cirrus SR22 cockpit (2003)

Cirrus SR22 intenrieur (2001)

Cessna 172 cockpit (2003)

Cessna 172 interieur (2003)

Figure 5-25: Comparison of cockpit and interieur of a 2003 Cirrus SR22 and a Cessna 172. © Cirrus Aircraft and Textron Aviation

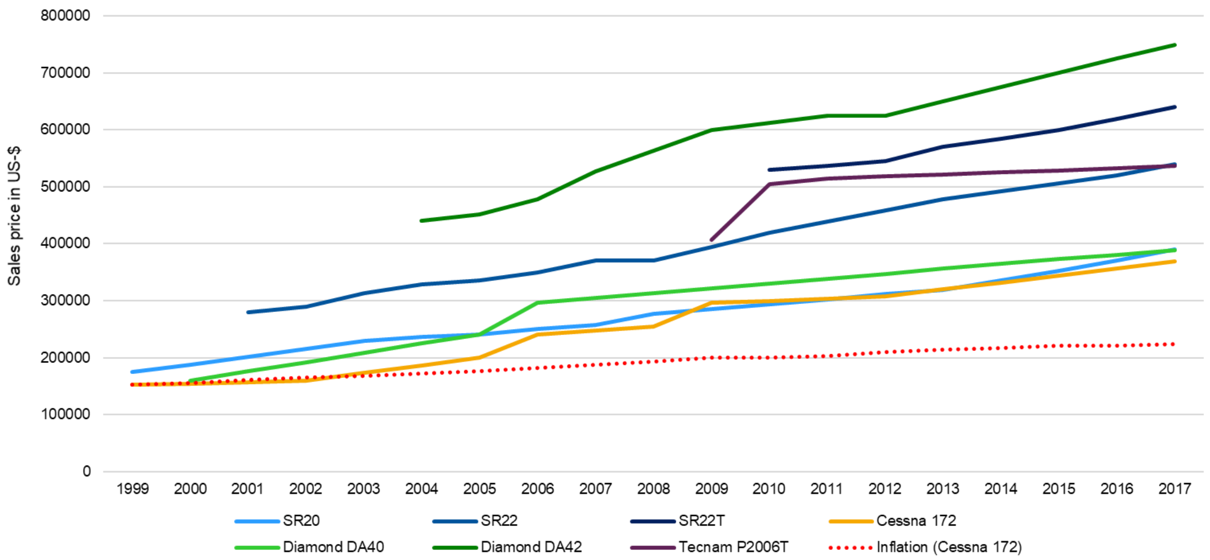

Figure 5-26: Sales prices of Cirrus aircraft in comparison with competitor pricing, 1999 to 2017

Overall a market entry of a new player into the General Aviation market is possible, if a convincing cost-benefit ratio can be provided for the customer and the technical level of competitors is surpassed.

5.10 Interim conclusion

In conclusion, two promising market segments will foster the market success of electro-hybrid aircraft such as ELICA: RAM and thin-haul air cargo services. Both market segments are expected to grow strongly and rely on existing airfield infrastructure and can help to shorten transport times for passengers and goods significantly. As the transport business is always focussing on cost, hybridisation can help to bring down energy cost and maintenance efforts for newly developed aircraft. Moreover, possible economic advantages may come up with future regulations or subsidies for environmentally friendly aircraft. To consider the fact that airfields and especially the local residents are not used to handle a high number of larger and therefore more noisy aircraft, low noise should be one design feature of ELICA. To provide flexibility for ELICA operators, a modular cabin design is favoured. Two promising future geographic markets are Scotland and Norway that are both fostering hybrid or fully electric aircraft. Finally, the example of Cirrus Aircraft was analysed to highlight that a technically competitive aircraft can open-up an existing market, even if higher prices are requested.

As a whole market success of an electro-hybrid 19-seater commuter aircraft will be strongly connected with its operational cost. Potential cost reductions due to electrification or benefits due to regulation cannot be taken for granted and should therefore not be the key arguments to start a new aircraft development. To analyse the economic potential of a 19-seater commuter aircraft, an in-depth analysis of a potential operator business case for ELICA is done in the next chapter.

6 Study on infrastructure and transport demand for ELICA

In this section the market potential and mission parameters such as take-off distance or airfield availability for thin-haul air transport will be evaluated. To do so existing airport infrastructure will be analysed in the form of runway lengths and how much people live in a set radius around the airfields in section 6.1. To that grid population data from the 2011 EU census and statistical data for the US is used and extrapolated to the total population in 2020.

To estimate the market structure for ELICA, a transport planning model is derived to assess feasible ELICA routes and compare them to other transport modes on a cost basis. This model considers the airfield infrastructure including runway surface and runway lengths. The existing infrastructure is then put into relation with population living around it. Following on, the model compares different transport modes such as car, CS-25 aircrafts and train to a RAM service such as ELICA. These findings are presented for Germany in section 6.2 as sufficiently detailed data on transport interdependencies is not available for other countries.

This study will be closed with a summarising interim conclusion.

6.1 Analysis of airfield and airport infrastructure

ELICA proposal defines 2,000 feet (ft) as technical required runway length for the analysis of airfield infrastructure. A safety factor (+25 %) for commercial air transportation is applied to this figure, and an additional factor is added to allow for a more realistic temperature window and altitude. In total, the required minimum runway length is set at 2,950 ft or 900 m.

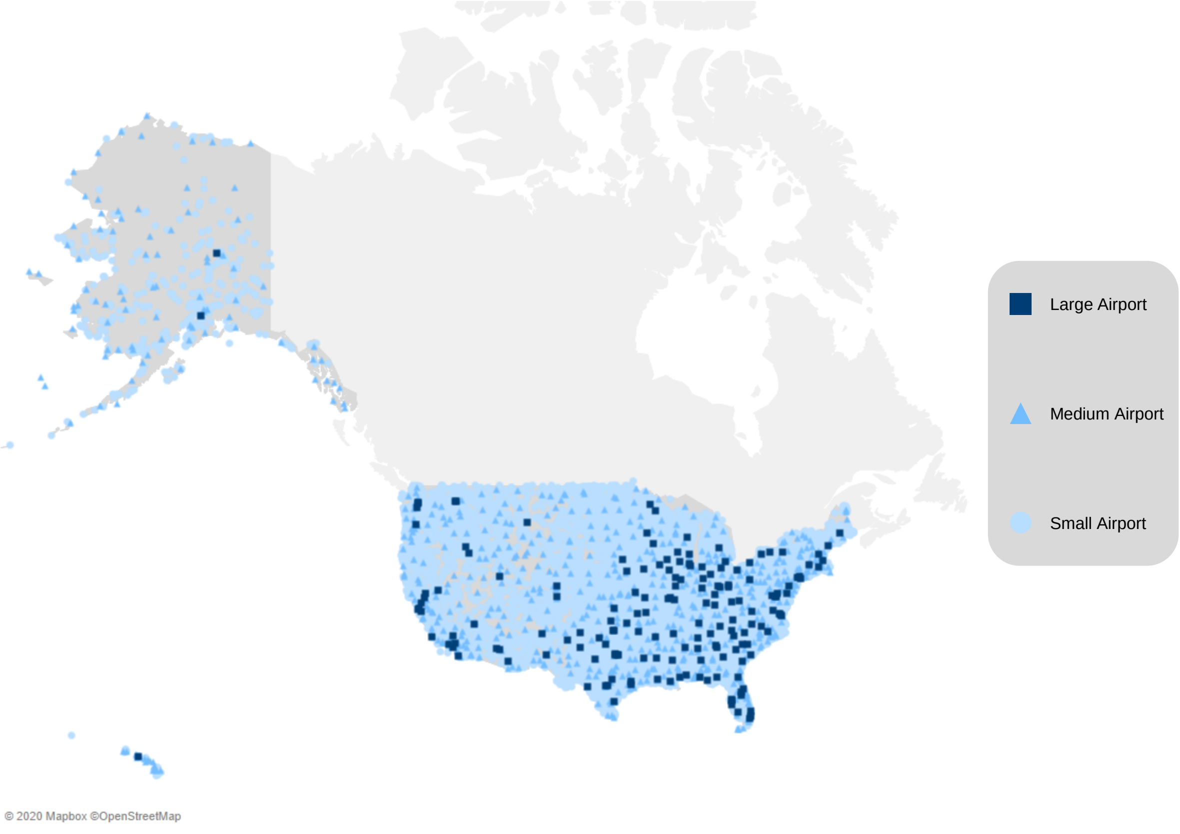

Figure 6-1: Airports in the USA based on ourairports.com open-source database

To collect data on airfield infrastructure an open source database[62] is utilised for worldwide airport and runway data. Other databases exist for single countries like Germany or France which yield more airfields (400 instead of 223 in the case of Germany). To assure comparability and consistency for all countries, data from ourairports.com was selected to arrive at a more realistic picture. This data can be considered consistent which is supported by the fact that the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) also provides it to Non-Governmental Organisations (NGOs) around the world to organise their efforts.[63] With this data the maps in Figure 5-5 and Figure 6-1 are created.

It is evident that the USA shows a denser network of airports compared to Europe and this is now further explored. Figure 6-2 shows that Europe has a lot fewer airports with short runways below 1,000 m. This can be attributed to a much more active GA community in the USA (cf. section 4.1). Above 2,000 m of runway length this disparity does not exist anymore and there are about the same number of airfields in each region.

In the next step it is examined how airfields are by studying how close the population lives to airfields. As large airports with likewise long runways are situated close to large population clusters the graphs do not fall as steeply in Figure 6-3 and Figure 6-4 as in Figure 6-2. It is evaluated which share of the population lives in radii of both 20 km and 30 km from airfields away in Figure 6-3 and Figure 6-4. Experience from earlier projects show that 20 to 30 km are a distance which can easily be driven by car or even taxi.

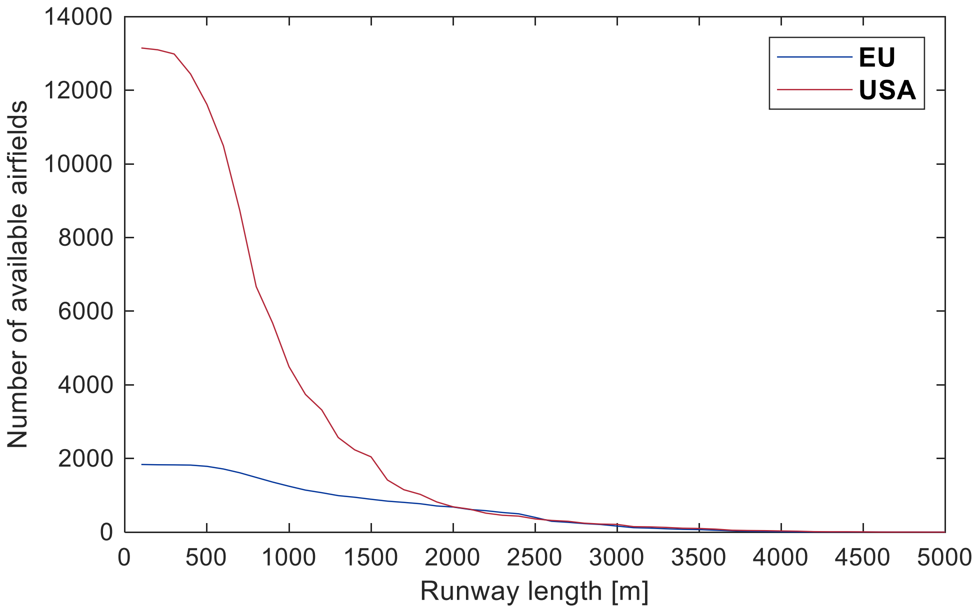

Figure 6-2: Comparison of airfield's runway length between USA and Europe

62 https://ourairports.com

63 https://data.humdata.org/dataset/global-airports

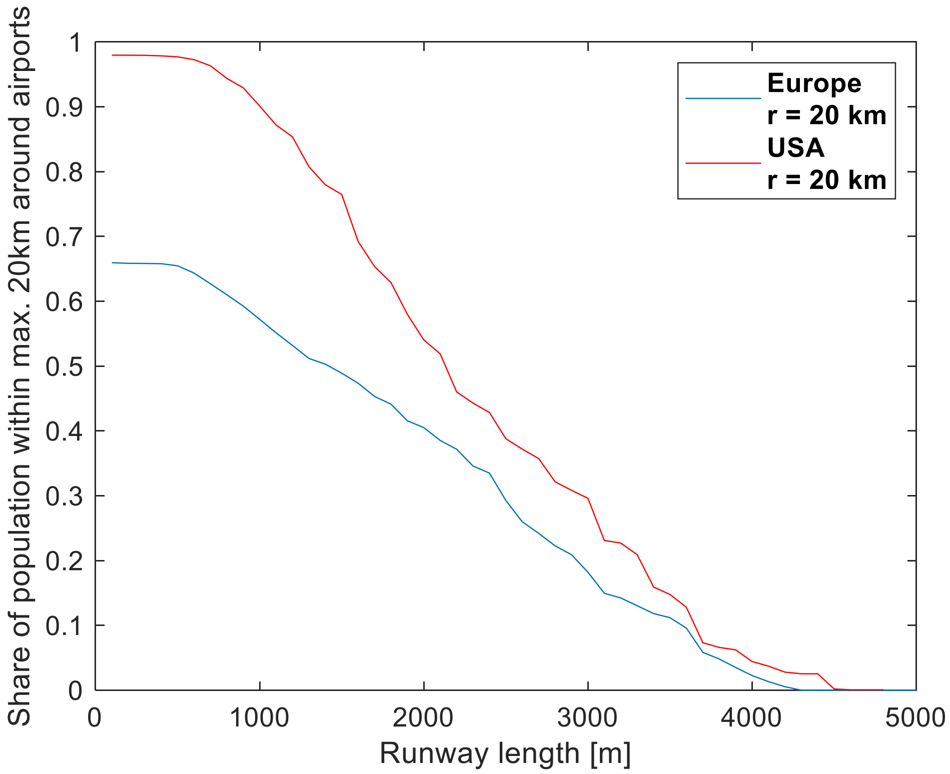

Figure 6-3: Comparison of share of population within 20 km radius around airfields in Europe and USA

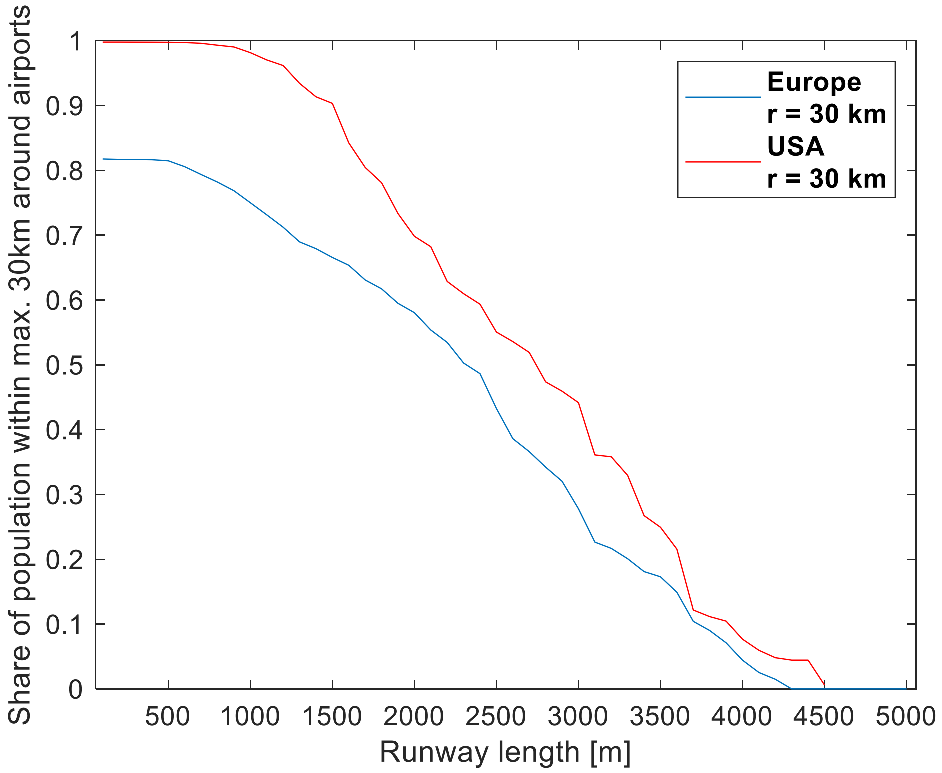

Figure 6-4: Comparison of share of population within 30 km radius around airfields in Europe and USA

The following four facts regarding accessibility and impacting the ELICA development can be derived from those figures:

- Almost the entire population of the USA (99.76 %) lives within 30 km radius of an airfield with a minimum runway length of 500 m; 97.71 % of the population of the USA lives within 20 km radius of an airfield with a minimum runway length of 500 m
- In Europe, 81.48 % of the population lives within 30 km radius of an airfield with a minimum runway length of 500 m, and 65.47 % within 20 km
- For the required minimum runway length of 900 m, 99.04 % and 92.93 % of the population of the USA are reached within 30 km radius and 20 km radius around an airfield, respectively
- In Europe, 76.86 % of the population lives within 30 km radius of airports with more than 900 m runway length; and 56.26 % within 20 km radius

Now a more detailed look is taken at European airports and four countries are compared to each other which are France, Germany, Belgium and the Netherlands (highlighted in orange in Figure 6-5). The countries are geographically very close, but Figure 6-5 shows that they have very different numbers of airports. While France and Germany have the most airports in Europe, the other two countries are at the lower end of the range. Moreover, sufficient statistical data was available for all four countries.

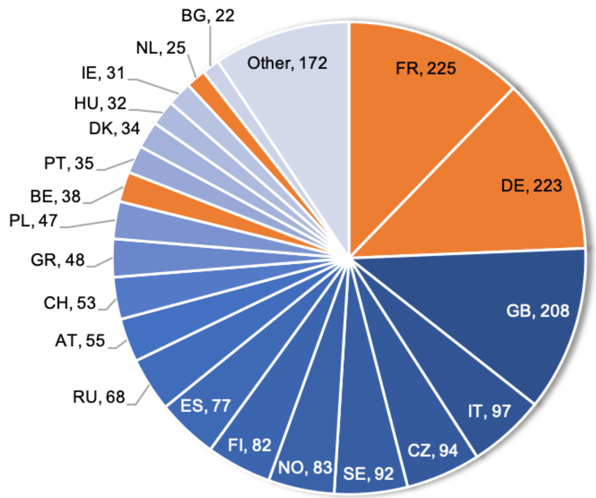

Figure 6-5: Airfields and airports in Europe per country

When comparing the absolute number of airfields as a function of their respective runway lengths in Figure 6-6 the two distinct country groups Germany, France and Belgium, Netherlands are clearly visible. When this analysis is done on a relative rather than an absolute basis in Figure 6-7 this distinction disappears, however. This shows that the share of short and long runways is very similar across all four countries. The graph for the European average is also added which corresponds closely to the four countries examined. Therefore, it can be assumed that this distribution of runway lengths holds true for all of Europe and that airfields are spread evenly across it.

Upon assessing the accessibility of airfields again for the four countries in focus in Figure 6-8 and Figure 6-9 this even spread continues. The following key facts about marginal differences between countries can be deducted when assessing a runway length of 900 m and more:

- Across all four countries airports are within 30 km distance for at least 80% of the population
- Airports are most accessible in Belgium, while 70 % are within a 20 km radius 95 % are with a 30 km radius
- Germany and the Netherlands change positions between the 20 km and 30 km radius. Though slightly more airports German airports are significantly more accessible at a 20 km radius with a share of 70 % of the German population and 60 % for the Dutch population, virtually the same share of the population can reach an airport within 30 km at 86.2 % and 86.1 % respectively
- In France still a very large share of the population can reach an airport within 20 km with 58 %, while 82 % can reach one within 30 km

Due to computational limitations in the model a person cannot cross borders to reach an airport, meaning that a person living Germany must always use a German airport. This does not always hold true in everyday life however and it is often less time-consuming to reach a foreign airport in Europe. This means that the above numbers are actually even better, and airports are even more accessible.

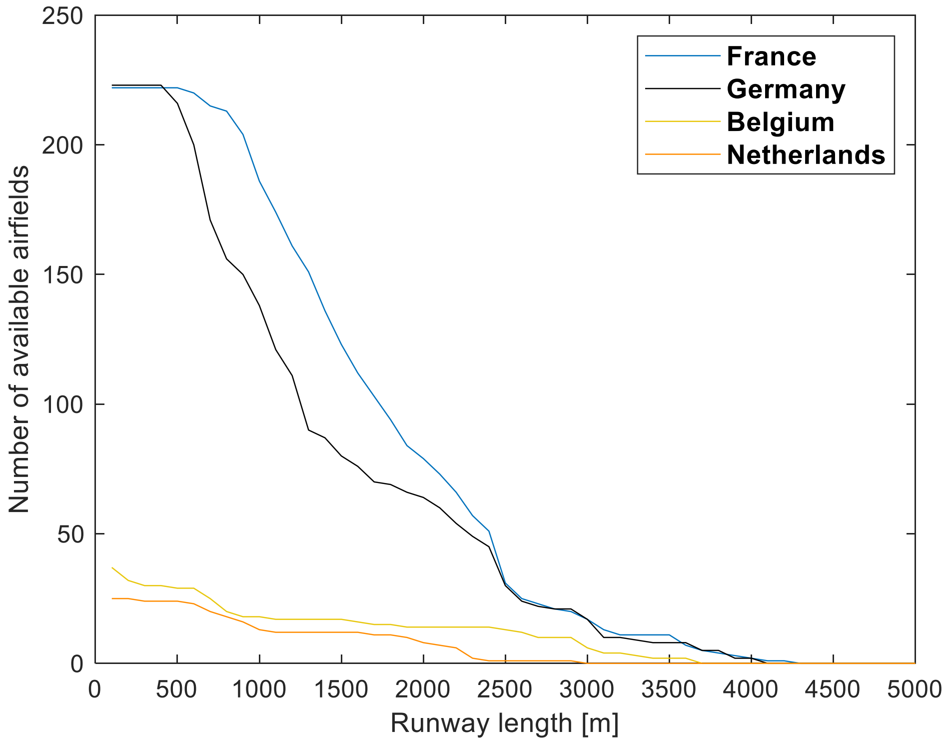

Figure 6-6: Comparison of number of available airfields as function of the runway lengths

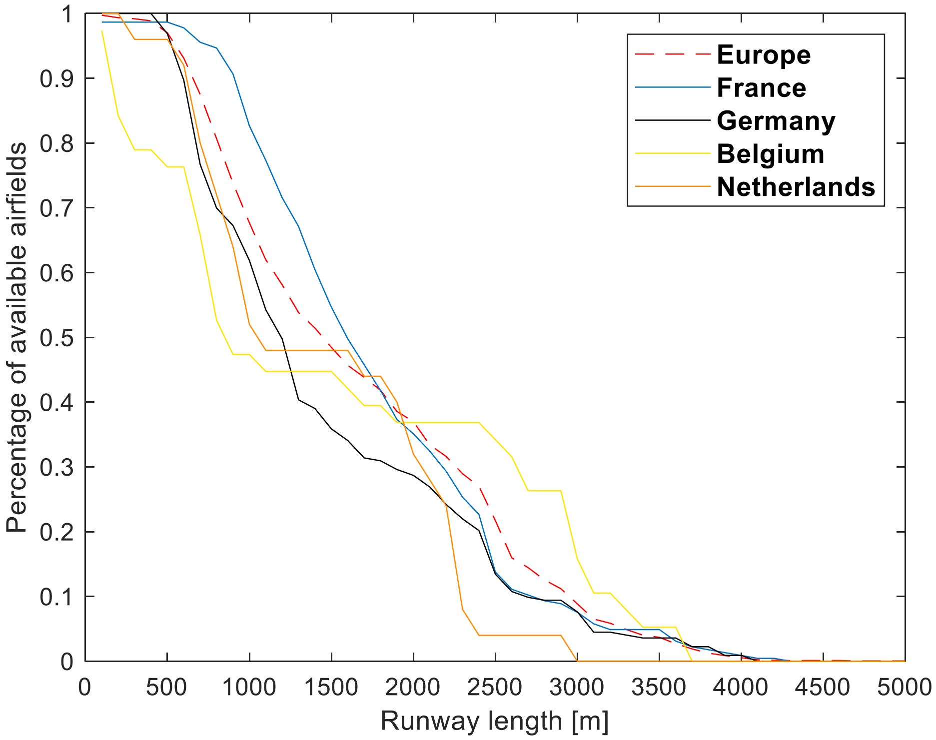

Figure 6-7: Comparison of relative number of available airfields as function of the runway lengths including Europe

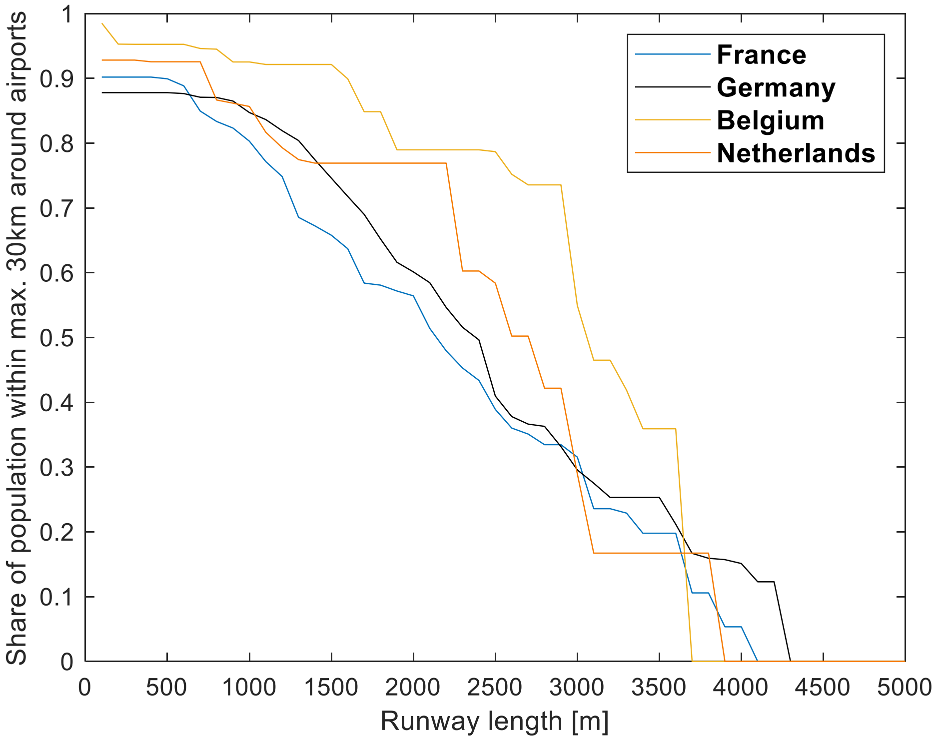

Figure 6-8: Share of population for selected countries within 30 km radius around the airfields

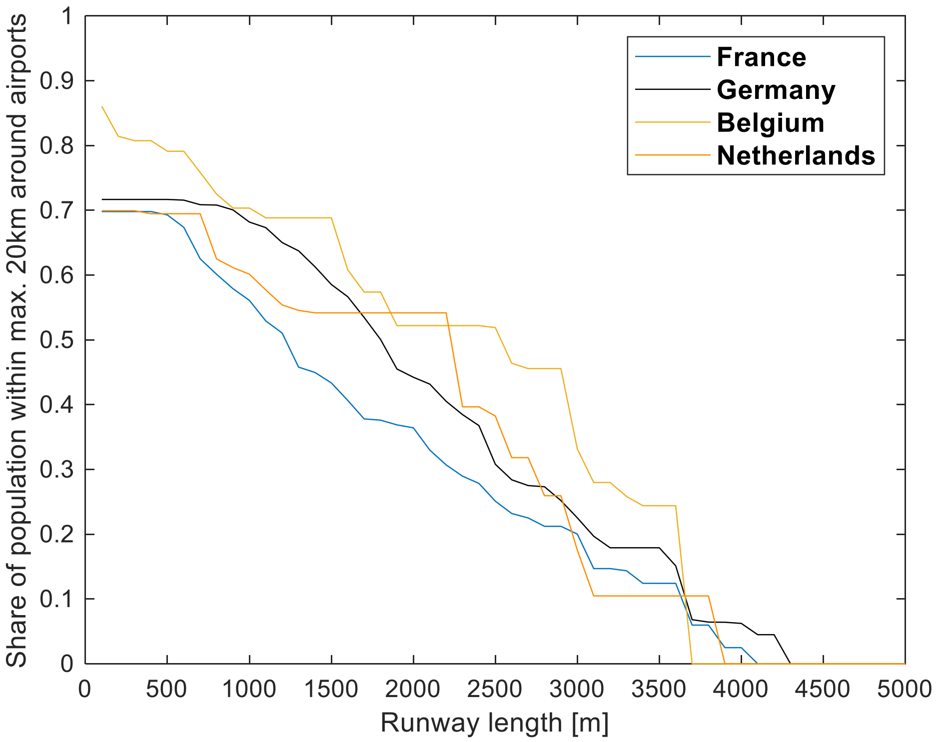

Figure 6-9: Share of population for selected countries within 20 km radius around the airfields

6.2 Analysis of transport demand for ELICA

The transport demand is now analysed for Germany, as quality data for transport interdependencies is available. Additionally, a more detailed picture of the available German airfields and airports can be given leading to more precise results. In the following, the key assumptions for the transport model are briefly explained.

If transport time for different modes of transport (car, train, CS-25 and CS-23 aircraft) are given for a specific route, the travellers may compare the travel time and travel costs of the available transport options. This is defined in the Value of Travel Time Savings (VoTTS) as the monetary value that the individual traveller is always willing to spend on travel time savings, which may lead to a switch to available means of transport. The correct quantification of this value is a key element in the whole model. It is assumed that socio-economic factors have a major influence on the individual VoTTS among other factors such as personal preference, e.g. avoiding planes due to agoraphobia or reluctance to travel by train. Further, business travel has a higher VoTTS than travel for leisure purposes. The socio-economic factors influencing the travel choice on a municipal level are the Gross Domestic Product (GDP) contribution per municipality as well as high-wage districts and districts with a variety of industrial companies.

For Germany, the Traffic Interconnection Forecast 2030 of the German Federal Ministry of Transport and Digital Infrastructure (BMVI) was selected to assess gross travellers on each route, independent of the means of transport. A traffic interconnection forecast is available on administrative-district basis (‘Landkreis’/’Kreisfreie Stadt’) or NUTS-3 level (a hierarchical level for dividing territory[64]).

64 https://www.destatis.de/Europa/EN/Methods/Classifications/OverviewClassification_NUTS.html

The 2011 census for Germany was utilised to discretise the population of each administrative district to clusters of each less or equal 100,000 inhabitants. As part of the publication of the census, population is available on a 1 km x 1 km grid. An example is the district of Euskirchen (Kreis Euskirchen), located southeast of Aachen (coloured yellow) and bordering on Belgium in the west with a total population of 187,940 as of 2011 (cf. Figure 6-10). The population of each square kilometre is represented as a circle with a radius proportional to its population. Based on the distribution, two clusters were determined, illustrated as a green cross; representing a population of 100,000 and 87,940, respectively.

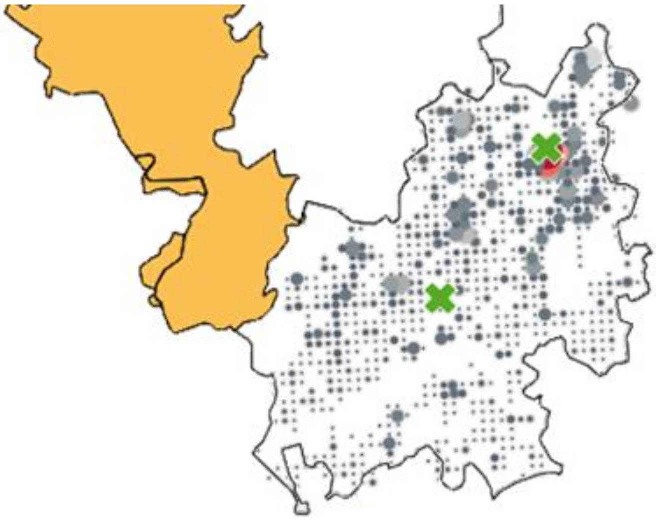

Figure 6-10: Discretisation of the district of Euskirchen district utilising clustering algorithms

Current travel modes for long-haul mobility comprise motorised private transport by car, long-distance train as well as CS-25 aircraft operated by commercial airlines. From Figure 5-3 it is known that certain areas of Germany have rather poor access to the long-haul networks resulting into long journey times for first and last mile. This may be addressed by ELICA using the airfields network presented in chapter 6.1.

In order to identify profitable routes a model is used in which a race across Germany from Aachen to Magdeburg takes place, illustrated in Figure 6-11. This results in the share of ELICA, long-distance train, car as well as CS-25 aircraft.

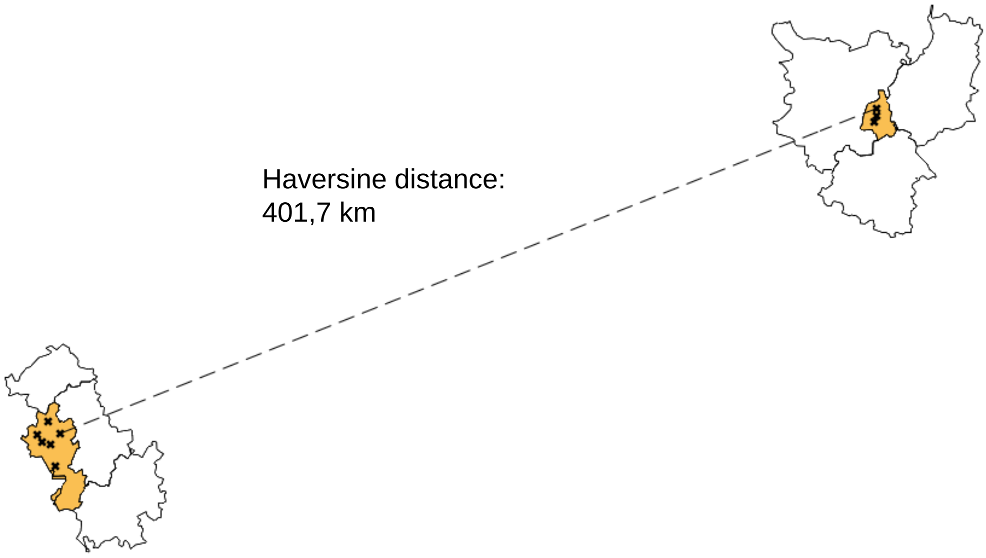

Figure 6-11: City of Aachen to City of Magdeburg, direct distance

The available modes of transports and their calculation methods are explained in the following and exemplified by Figure 6-12 that gives an overview of all transport modes.

The simplest travel mode is by car. The journey begins in the origin cluster and ends in the destination cluster, using the fastest road connection provided by the infrastructure available. The distance and travel time are determined by a route plan provider API.

Long-distance train connections consist of a first and last mile and the actual train route. The first and last mile is again computed by car via API from the origin/destination clusters to the long-distance train stations. Inbound trip is calculated with cost for a private car, outbound trip with cab cost. The train route, its duration and pricing are queried based on the Deutsche Bahn API by requesting a first-class ticket for the next day. The pricing is fixed and independent of booking date.

For flights on CS-25 aircraft, only routes actually operated by an airline are taken into account. It is assumed that the flights are operated independent of the time of day. An approximate variable flight fare per seat of 22 ct/km was calculated by averaging the connections offered in Germany per day. A cruise speed of 833 km/h (or 0.78 Mach) is assumed. For computational reasons a fixed cruising altitude is set at 11,000 m and not dependent on flight distance like in actual service, the rate of climb is specified at 8 m/s and the rate of descent at 8.9 m/s; during climb and descent a horizontal approach speed of 350 km/h is fixed. This results in horizontal distances during climb and descent of 133 and 120 km, respectively. If the total flight distance is below the sum of these, the flight will never reach cruising speed. First and last mile are calculated the same way as for long-distance trains. For the trip Aachen-Magdeburg, airports of Cologne and Berlin were addressed.

ELICA is calculated like CS-25 flights, except that it is assumed that all airfields in Germany with the required minimum runway length of 900 m are operational for ELICA, regardless of operational airlines or the time of day. The variable flight fare per seat is estimated at 53 ct/km. An average cruise speed of 375 km/h is defined, and a horizontal approach speed of 150 km/h during climb and descent. To reach FL100 (10,000 ft, ~ 3,000 m), a vertical climb and descent rate of 8 m/s is determined. A total waiting time of 30 minutes for check-in, apron taxi time, and luggage handout is set. First and last mile is again calculated the same way as for long-distance trains.

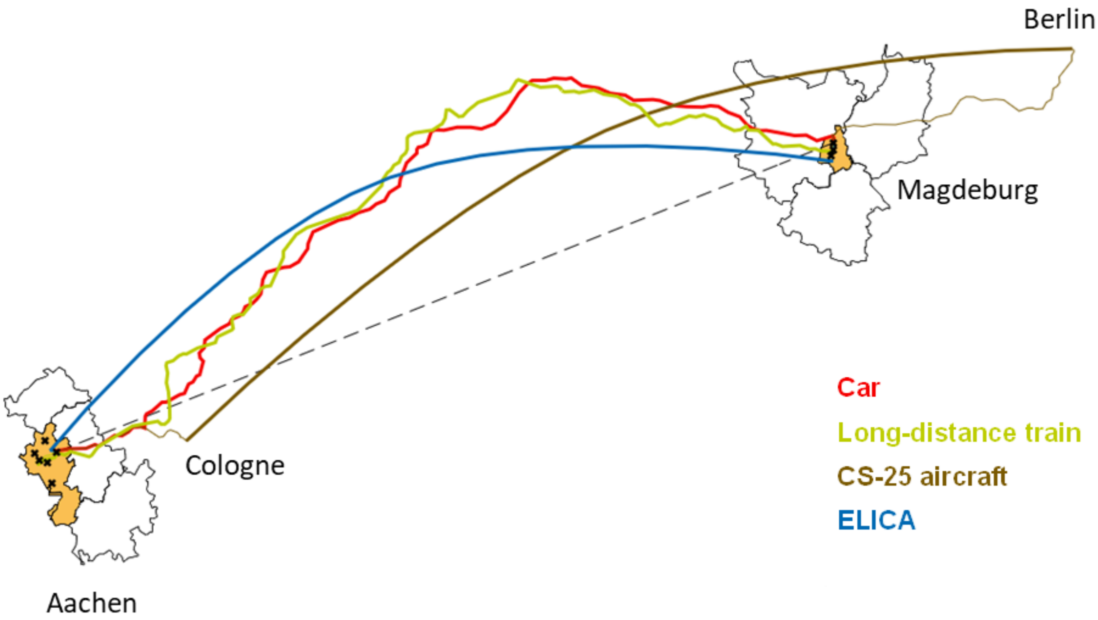

Figure 6-12: Overview of available transport modes and corresponding routes for the example trip Aachen-Magdeburg

This example should clarify the approach of the applied transport model. Such a computed calculation was performed for every possible connection between German counties.

To assess the market potential of ELICA, trip duration and travel cost are computed for all transport options on all routes using statistical models and APIs. Based on the given values, the distribution of the selected means of transport is calculated per route for all passengers. This figure gives an indication of the profitable routes where ELICA can be applied in Germany. These findings can be used for a first market size assessment and can be scaled to European level via GDP distribution.

Figure 6-13 presents the connections between clusters for which the model has calculated a dominant market share for ELICA. The bigger the depicted circle the more of the about 1,100 clusters can be reached with a dominant market share of ELICA.

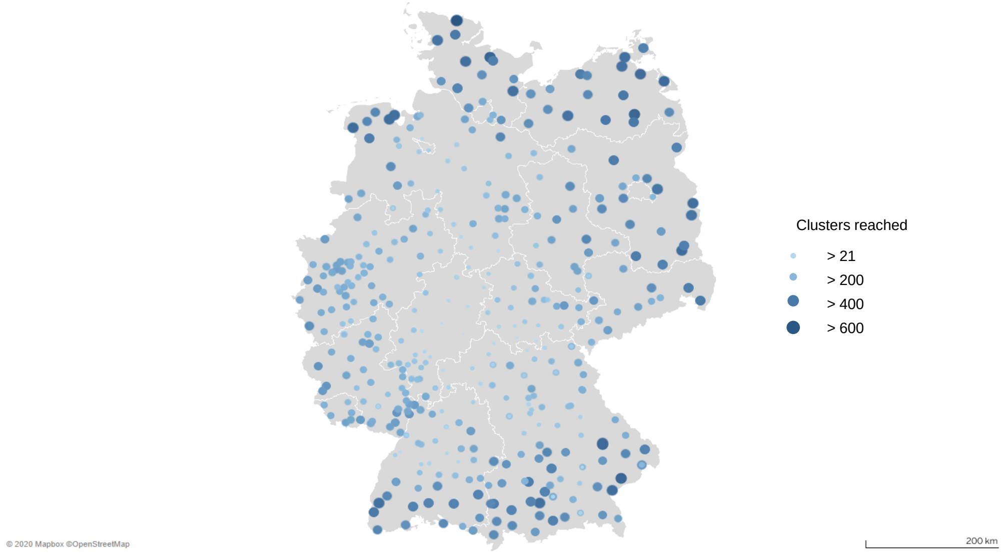

Figure 6-13: Number of ELICA-profitable clusters reached by each administrative district in relation to its size

The following regions within Germany have been identified for which ELICA can provide a massive improvement to the infrastructure:

- German coastline (north of Lower Saxony, Schleswig-Holstein and Mecklenburg-Vorpommern),
- German states of Brandenburg and Saxony-Anhalt, plus North-western part of Thuringia, Southwestern part of Lower Saxony
- Rhine-Neckar Metropolitan Region around the cities Mannheim, Ludwigshafen and Heidelberg
- South of Baden-Württemberg around the major cities of Freiburg and Tübingen
- South of Bavaria (Swabia, Upper Bavaria, Lower Bavaria) with an exception of the city of Munich
- Western parts of North Rhine-Westphalia around the cities of Aachen and Mönchengladbach

To exemplify a region for which ELICA can provide added value to the infrastructure a detailed look is taken at the city of Aachen. All cities for which an ELICA connection from Aachen city centre is most suitable from the VoTTS perspective (ELICA is the dominant means of transport) are shown in Figure 6-14 and Figure 6-15. In total, 405 clusters (of 1010) located in 201 administrative districts are dominated by ELICA with the cluster distance ranging from 191 km to 642 km, and an average direct cluster distance of 440 km. From Aachen the following regions would be reached in a dominant manner by ELICA:

- Eastern states of Germany (TH, ST, SN, BB, BE, MV)
- Within North Rhine-Westphalia (federal state of Aachen), only the upper east around the city of Bielefeld is profitable for ELICA
- North of Hesse around the city of Kassel
- Rhine-Neckar Metropolitan Region around the cities Mannheim, Ludwigshafen and Heidelberg
- German coastline except the area between Bremerhaven and Hamburg
- Southern and Eastern Baden-Württemberg
- Bigger parts of Southern Bavaria as well as some parts of Northern Bavaria (Franconia)

Figure 6-14: ELICA VoTTS-optimal administrative districts from Aachen city centre cluster

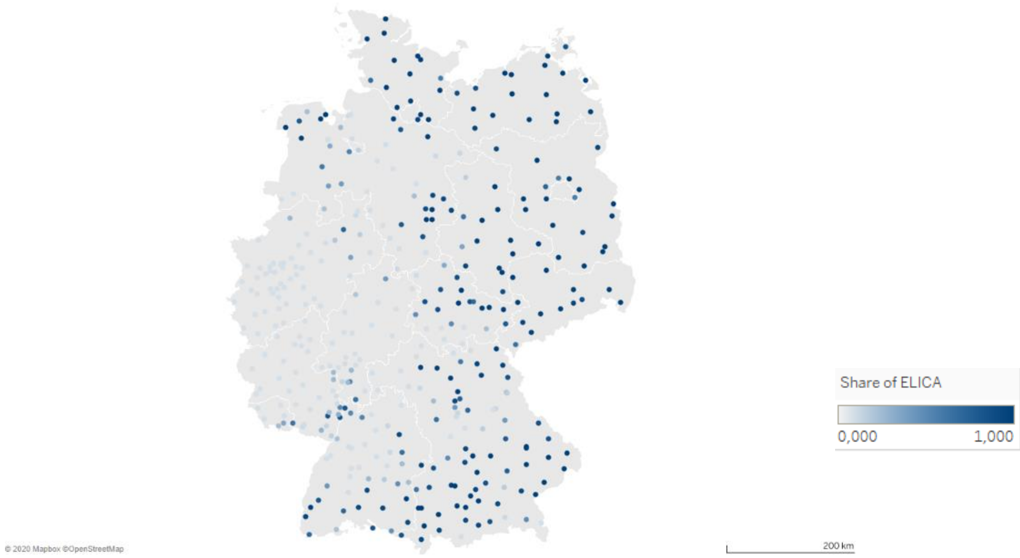

Figure 6-15: ELICA share regarding VoTTS-optimisation for administrative districts from Aachen city centre cluster

Overall, the following distribution of the preferred means of transport is calculated for Germany depicted in Figure 6-16. Dominant mode of transport is the car due to its flexibility and low cost. If the assumed revenue per RPK of 0.53 Euro can be reached, a market share for business trips of about 30% for ELICA can be derived. Average mission length is about 370 km.

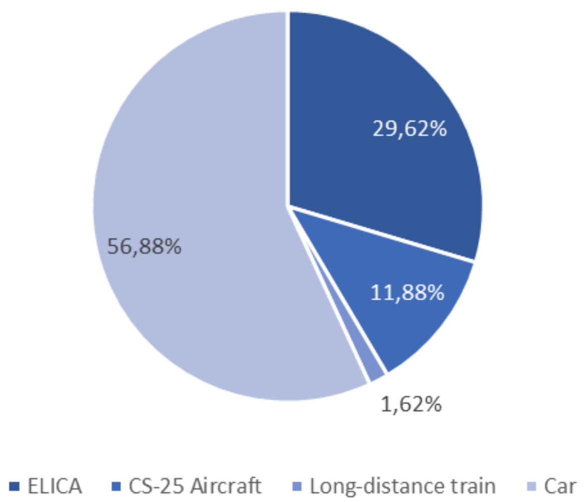

Figure 6-16: Model results for Germany with share of the preferred means of transport per route

When looking at historical data from Figure 6-17 it can be seen that in 2018 56% of flights operated in scheduled passenger transport by 19-seaters had a distance of less than 200 km while 83% had a distance of less than 350 km.

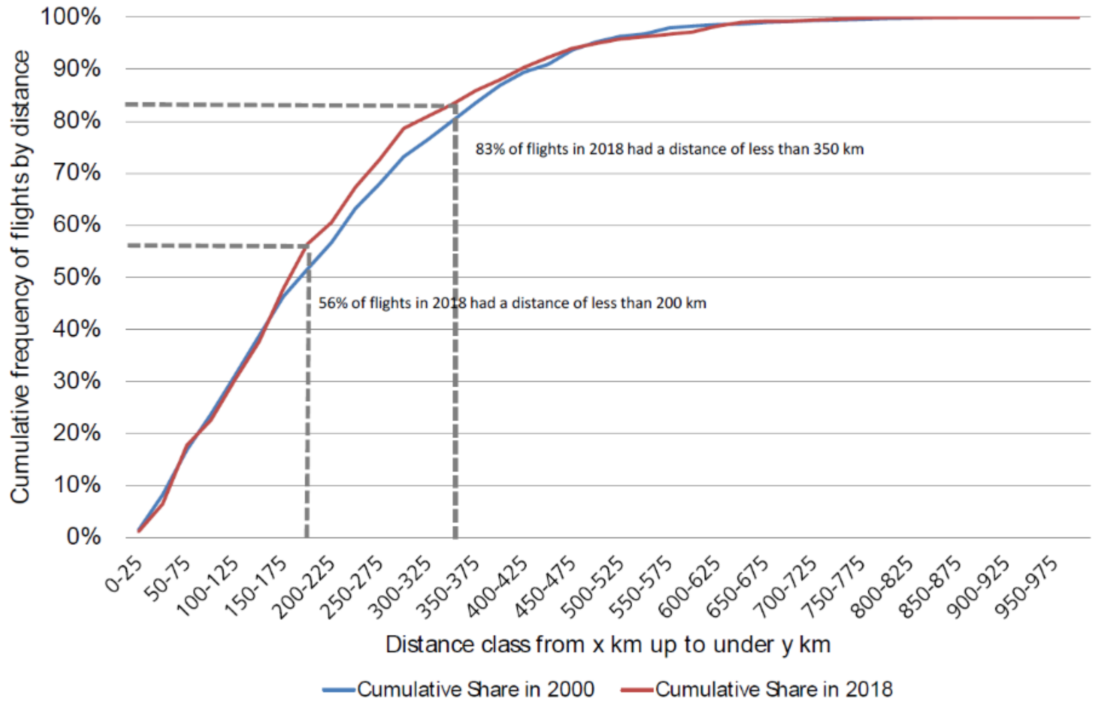

Figure 6-17: Cumulative share of scheduled passenger flights with 19-seater aircraft by distance 2000/2018. © DLR[65]

It has to be highlighted that most of the 19-seater commuter aircraft were used for comparably short routes, e.g. 'island hopping'. Therefore, a longer trip distance for ELICA can be assumed as it will be addressing new market segments (cf. sections 5.1 and 5.2).

[65] DLR final report on 19-seater commuter research project with Bauhaus Luftfahrt

6.3 Interim conclusion

It was shown that the required runway length of 900 m is sufficient to approach a large number of European and US airfields. Detailed data can now be provided for technical design and requirement definition of ELICA. A deep dive was performed for Germany, France, Belgium and the Netherlands driven by the countries size and data availability. Similar results were found.

A transport model was set up to compare transport by car, train, CS-25 aircraft and ELICA and was exemplified for the city of Aachen. Results of the analysis of the German business transport demand show that a mission share of ELICA of about 30 % is in reach, if foremost the revenue and cost requirement of 0.53 Euro per RPK can be met as well as the technical assumptions such as cruise speed or required runway length. Average flight distance is estimated to be about 370 km.

Considering inaccuracies and maybe too optimistic assumptions, a relevant market share for RAM services as ELICA can be predicted. As airfield availability in the rest of Europe and even in the US is comparable to the German situation, the derived findings can be extrapolated to European and US level. Experience from previous projects shows that the GDP is a feasible translation factor as it is available in a comprehensive quality and gives a good indication of the wealth and business situation in a specific country or world region. Before an initial and conservative sizing of the market for ELICA is done, the assumed price of 0.53 Euro per RPK needs to be validated for an operator business case that is calculated in the following chapter.

7 ELICA Business case

To provide a realistic and conservative estimation of feasible operation cost and revenues for ELICA from an operator perspective, a business case is calculated within this chapter. First, major assumptions and derived KPIs are presented and discussed. Second, main cost driver are identified and sensitivity analysis for key variables are executed. Third, an initial sizing of a market for ELICA in terms of sold aircraft p.a. is derived from the findings of chapters 6 and 7. The chapter is closed with an interim conclusion.

7.1 Availability and utilisation of ELICA service

Before cost can be assumed and calculated, the average availability and utilisation of an ELICA from an operator perspective needs to be assessed. The average day length in Central Europe is 12 hours and 9 minutes and correlates with the service hours of most airfields.[66] To take a conservative approach, the duration of an average operational day (OD) is assumed to be 10 hours. Mission time per OD is set at 2/3 of the available work hours based on expert judgment. Time must be considered for planned downtime, mission preparation and debriefing. For the average mission distance the average of three values is used that cover all realistic scenarios – from 'long-distance' thin-haul air service over business travel within RAM to 'island hopping', as shown in Table 5 and set to 435 km. Average cruise speed is assumed to be 375 km/h as used for the transport model. These two values set up the ELICA reference mission.

Table 4: Average mission distance for ELICA [5 9]

Hofmann et al. for Do 228NG	740 km
Transport study for Germany	370 km
Grimme et al. for hybrid 19-seater	200 km
Average mission distance	**435 km**

Statistical data on the actual utilisation of Do 228 aircraft by US-airline VisionAir can be used to provide realistic assumptions. VisionAir has reported a utilisation per aircraft of 74 % and a taxiing time per mission of 0.15 hours for the period 2010 to 2015.[67] DLR has reported an average utilisation rate for the TOP-30 airlines worldwide of 80.19 % in 2014.[68] Kreimeier has assumed an utilisation rate for his air taxi service in Germany of 80 %. [9] Considering all identified values the utilisation rate for ELICA was set to 75 %. For the entire ground handling per mission (taxiing, entry and exit of the aircraft, etc.) 0.5 hours were considered.

Table 5: KPIs derived from US-airline Vision Air[69]

Available seat miles per aircraft	851,153
Revenue passenger miles per aircraft	634,153
Utilisation per aircraft	74%
Taxiing per aircraft per mission	0.15 h

VisionAir also reported that they experienced a share of revenue missions of 100 %. To take again a conservative approach, this value was set to 75 % for ELICA to consider empty

66 https://btmdx1.mat.uni-bayreuth.de/kcm/data/Materials/FertigeLernumgebungen/Tageslaengen.pdf

67 Vision Air stopped service in 2017, but the period from 2010 to 2015 is assumed to be applicable

68 DLR report on air traffic 2014: https://www.dlr.de/fw/Portaldata/42/Resources/dokumente/aktuelles/Luftverkehrsbericht_2014.pdf

69 Statistical data on Do 228 usage of Vision Air: https://data.visualapproach.io/T2_Export/Export/ ; https://www.transtats.bts.gov/TableInfo.asp

positioning flights. Figure 7-1 depicts the assumed time usage per OD for ELICA. 5.5 hours per OD were spent with direct passenger service and 4.7 hours are flight hours per OD.

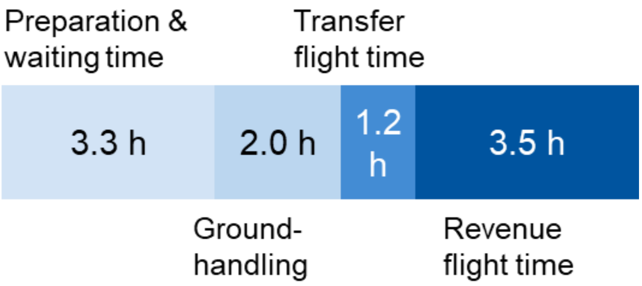

Figure 7-1: Assumed time usage for an average operational day of ELICA

ELICA operations are assumed to occur during all working days and on half of Saturday (morning) and half of Sunday (afternoon) as the transport of businesspeople is in focus. Moreover, an average uptime of ELICA of 95 % is applied based on expert assessment to quantify planned down time for maintenance, etc. Table 6 summarises the described assumptions and provides calculations for relevant KPIs such as flight hours p.a. (1,380 h) and RPK p.a. (5,534,065).

Table 6: ELICA utilisation assumptions and KPIs

Hours of work per Operational Day (OD)	10 h
Mission share per OD	67 %
Avg. mission distance	**435 km**
Avg. cruise speed	**375 km/h**
Ground handling per mission	0.50 h
Avg. mission duration	**1.66 h**
# missions per OD	4.02
Share of revenue missions	75 %
# revenue mission per OD	**3.01**
Avg. utilisation rate	75 %
PAX/revenue mission	**14.25**
# PAX per OD	42.92
OD per week	6
Uptime ELICA	95 %
OD p.a.	296.4
Flight hours per OD	4.66 h
Flight hours p.a.	**1,381 h**
Revenue flight hours p.a.	1,036 h
PAX p.a.	12,722
RPK p.a.	**5,534,065**

7.2 Cost of aircraft operation

Next, the cost of aircraft operation are calculated. These cost can be split up into the following three groups and are discussed in sequence of appearance:

- Cost per flight hour
- Cost per mission
- Fixed cost p.a.

Most important driver for cost per flight hour are energy cost. In order to calculate the fossil (JET A-1) and electric energy needed to perform the reference mission a mission energy calculation is conducted. This yields the total mission energy required for the flight time and with a given split between fossil and electric energy also the consumption.

The reference mission energy calculation is based on information that is stated in the airplane flight manual (AFM) of a reference aircraft with similar configuration, in this case the British Aerospace (BAe) Jetstream 32 airliner. The Jetstream 32 is an improved version of the Jetstream 31 and conducted its first flight in 1988. The Jetstream series aircrafts are commuter category aircrafts with a two-person cockpit and up to 19 passenger seats. Both aircraft feature the same low wing twin turboprop design, with a cruciform tail and retractable landing gear. The 32 variant however introduced an improved version of the Honeywell TPE331 turboprop engine. The aircraft is equipped with a pressurised cabin. Chapter 14 of the Jetstream 32 AFM is titled flight planning and contains detailed manufacturer data on aircraft performance. Among them is information about sector fuel and time with is defined as follows:

‘Sector fuel and time is the fuel and time for take-off and acceleration to climb speed, climb, cruise and descent to the destination. The tables on pages 14-2-4 to 14-2-19 show sector fuel and time, as functions of distance and cruise flight level, for a range of temperatures. The ground distance table printed opposite each fuel and timetable is based on the stated wind at cruise flight level and 70% of that wind in the climb and descent. The take-off weight used to derive the tabulated figures is either that for maximum payload or 16,204 lb whichever is lower.’

The sector fuel tables allow for a realistic fast look up of necessary fuel amounts as a function of the most relevant mission parameters. Additional fuel and time for pre take-off and post landing taxi hast to be added, which is set at 60 lb and 10 minutes total. Additional tables for diversion fuel and reserve fuel are provided, however not necessary for mission energy calculation. To study possible advantages in fuel consumption the calculation is done for two different cruise pressure altitudes. One for FL210, which is equivalent to 21,000 ft pressure altitude and one for FL110 which is equivalent to 11,000 ft pressure altitude. Since the first flight of the aircraft was 1988 a conservative technical upside potential for increased fuel efficiency of 5% has been added. With those assumptions a block fuel of 364.12 kg is calculated for cruising at FL 210, while 414.11 kg is necessary for cruising at FL 110. The flight level times 100 is equivalent for the pressure altitude at which the aircraft is flown. The sector flight time plus taxi is at 82.5 minutes slightly longer for the FL 210 cruise, compared to 79 minutes for cruising at FL 110. That is due to the longer time that is spent in climb and decent, as well as a slightly lower cruise speed because of the lower engine output power at higher altitudes. By using the density and specific energy of Jet A-1 a total amount of fossil fuel energy required can be calculated.

To calculate the energy that is delivered on the propeller shaft during the mission, losses on conversion of the fossil fuel energy to rotational energy must be considered. Those losses are quantified by the specific fuel consumption of the turboprop engine, which can be converted into an efficiency. With an efficiency of 26% for the installed TPE331-12UHR engine the total mission energy provided at the propeller shaft is calculated to 1,146.78 kWh and 1,295.24 kWh respectively.

Table 7: Energy consumption per ELICA reference mission

	Flight Level 210		Flight Level 110	
Parameter	Value	Unit	Value	Unit
Mission distance	500.00	km	500.00	km
Reference aircraft	BAe Jetstream 32			
Block Fuel w/o taxi[70]	785.00	lb	901.00	lb
Taxi	60.00	lb	60.00	lb
Fuel consumption upside potential	5	%	5	%
Block Fuel	802.75	lb	912.95	lb
Block Fuel	364.12	kg	414.11	kg
Density Jet A-1[71]	0.81	kg/l	0.81	kg/l
Block Fuel	449.53	l	511.24	l
Specific energy Jet A-1[71]	12.03	kWh/kg	12.03	kWh/kg
Fossil energy amount	4,380.38	kWh	4,981.71	kWh
Sector time + taxi (Both AFM)[70]	82.50	min	79.00	min
Average speed	363.64	km/h	379.75	km/h
Fuel consumption / 100 km	89.91	l/100 km	102.25	l/100 km
Fuel consumption / h	326.93	l/h	388.29	l/h
SFC TPE331-12UHR[72]	0.52	lb/hp/h	0.52	lb/hp/h
Fuel energy (0.522 lb)	2.85	kWh	2.85	kWh
Energy / hp / h	0.75	kWh	0.75	kWh
Efficiency TPE331-12UHR %	26	%	26	%
Total mission energy	1,146.78	kWh	1,295.24	kWh
Percentage of electrical energy	15	%	15	%
Mission energy fossil	974.77	kWh	1,100.96	kWh
Mission energy electric	172.02	kWh	194.29	kWh
Efficiency electric powertrain	90	%	90	%
Energy from batteries / Mission	191.13	kWh	215.87	kWh
CO_2 per kg Jet A-1[73]	3.15	$kgCO_2/kgJetA$	3.15	$kgCO_2/kgJetA$
CO_2 w/o hybrid /Mission	1,146.98	kg	1,304.44	kg
CO_2 with hybrid /Mission	974.93	kg	1,108.77	kg
CO_2 savings	172.05	kg	195.67	kg
CO_2 w/o hybrid /h	834.17	kg/h	990.71	kg/h

70 BAE Systems - Jetstream 3200 Series Manufacturers Operating Manual – Chapter 14 Flight Planning
71 Aviation Fuels Technical Review - Chevron Products Company
72 AviationWeek Gas Turbine Engines January 2008 TPE331-12UHR
73 European Environment Agency CORINAIR manual (2001)

CO_2 with hybrid /h	709.04	kg/h	842.11	kg/h
Fuel with hybrid / Mission	382.10	l	434.56	l
Fuel with hybrid / h	277.89	l/h	330.04	l/h
Fuel with hybrid /100 km	76.42	l/100 km	86.91	l/100 km

Considering that 15 % of the mission energy should be provided by an electric powertrain, the required energy that must be provided by the electric powertrain can be calculated to 172.02 kWh and 194.29 kWh respectively. For the calculation of the energy provided by batteries the efficiency of the electric powertrain must be taken into consideration. With 90 % efficiency this results into 191.13 kWh and 215.87 kWh respectively.

The required amount of fuel is reduced in turn and yields a fuel flow per hour of 277.89 l/h and 330.04 l/h respectively. With a CO_2 amount of 3.15 kg CO_2 /kgJet A-1 the CO_2 savings due to hybridisation can be calculated to 172.05 kg and 195.67 kg respectively. Even though the method used is only a first order of magnitude consideration it allows for a rough estimate of the energy that is necessary for such a mission.

For the further calculations, an unpressurised cabin and an average cruise speed of 375 km/h is assumed. Hence, the hourly fuel flow is set to 325 litres. As ELICA will perform Commercial Air Transport, it will be freed of energy taxes. Therefore, a net price per litre JET A-1 of 0.95 € was derived.[74] Cost per kWh are set to 0.22 € for a consumption of 215 kWh per mission.[75] As it is currently unclear how much electrical energy will be needed for take-off and climb and how much will be used for cruise, the cost for electrical energy are considered later on for the mission cost.

Further main cost drivers per flight hour are the reserves for the engines as well as for maintenance. Here, realistic values can be cited from the Operations Planning Guide for a broad set of aircraft, ranging from piston engines over turboprops to business jet provided by the magazine Business & Commercial Aviation.[76] As reference aircraft the Cessna Grand Caravan, the DHC-6-400, the King Air 350ER and the Swearingen Merlin IVC are respected. Differences between those aircraft are considered for the benchmark (e.g. just one engine mounted in the Grand Caravan). Based on this data, maintenance reserve is set to 176 €. The engine reserve was reduced by a factor of 7.5 % to consider the reduced maintenance cost for hybrid powertrains as described in section 5.3. Hence, a value of 202 € was set.

A further benchmark value is the propeller reserve that is set to 16 €. Depreciation is calculated based on an ELICA net-price of 6 million € (comparable to existing 19-seater commuter aircraft), a linear depreciation period of 21 years according to German tax law and a residuum value of 10 %.[77] Depreciation cost per flight hour of 186 € are calculated. To consider inaccuracies the position ‘other cost’ was set to 5 % of the calculated cost (also applied for mission and fixed cost). Cost share per flight hour is given in Figure 7-2. The total value is set to 933 € per flight hour or 2.49 € per flight km.

Besides the cost per flight hour the mission cost needs to be calculated as well. Major cost drivers are air airport fees and air traffic fees.

As airport fees are an essential part of operating cost, they were analysed for eight airports across Europe with 0.7 to 2.3 million yearly passengers. The output figure are the airport fees per rotation, comprising landing, off-loading, on-loading and take-off. The cost is given per

[74] Fuel price taken from: http://www.flugplatz-hassfurt.de/navid.14/flugbetriebsstoffe.htm
[75] Electricity price taken from verivox.de for professional usage (net price)
[76] http://pages.bcadigital.com/OPG17?em=11117&code=OPAWS
[77] https://www.lexoffice.de/service/abschreibungstabelle/flugzeuge-unter-20-t-hoechstzulaessigem-fluggewicht/

rotation for greater comparability as some cost only occur for departing (security checks for example) and others for arriving passengers. While some airports also have fixed cost per landing others have fixed cost per take-off. Further the cost are split into base fees and cost which arise per passenger. It has to be noted that major handling fees are excluded since their system of calculation varies greatly and it would have exceeded the scope of this project to create a model to make such cost comparable.

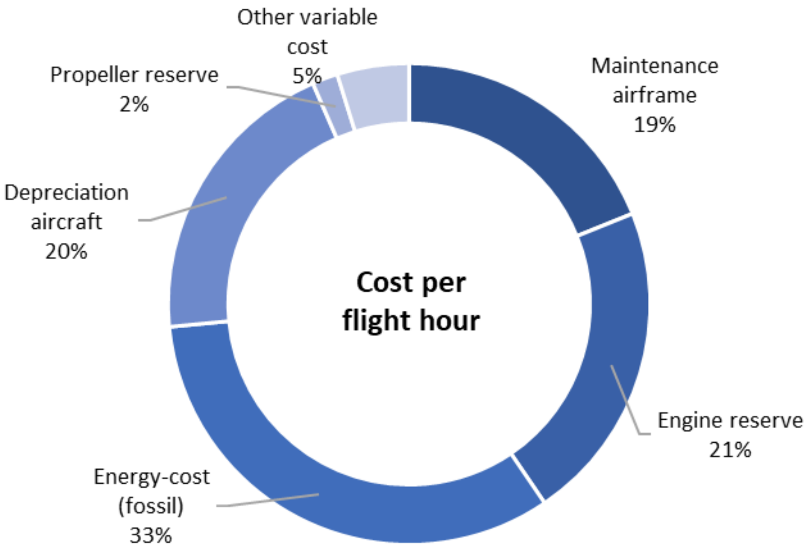

Figure 7-2: Calculated cost share per flight hour

When calculating the fees, a load factor of 75 % is assumed and that the flights are intra-European (otherwise cost for passport checks need to be added). Further it is also assumed that the aircraft is state-of-the-art and therefore always part of the noise class with least noise emission. On average airport fees excluding handling cost will stand at 168.72 € per rotation for the ELICA reference mission.

An expenditure for aircraft operators that is always present are moreover air traffic fees. Those fees are paid to air traffic control organisations which guarantee that the airspace is always safe and secure to use. In Germany the air navigation services are outlined in the German Aviation Act (LuftVO). The air traffic fees are comprised of two charges. One for approach and departure services and one for en-route services. Terminal charges are levied by the air navigation services for providing services and facilities to airlines during take-off and landing at German airports.

The charge to be paid is a function of MTOM in metric tons and a unit rate that is published yearly in the relevant regulations. For 2020 the unit rate in Germany is set to be 126.29 €.

$$charge = \left(\frac{MTOM}{50}\right)^{0.7} \cdot unit\ rate$$

Table 8: Airport fees across Europe[78]

Airport	IATA code	Country	Yearly passengers (last year reported)	Base fee [€]	Passenger fee [€]
Trieste	TRS	Italy	772,517	28.80	12.94
Rennes	RNS	France	856,791	48.22	5.98
Münster/Osnabrück	FMO	Germany	986,260	75.00	8.65
Innsbruck	INN	Austria	1,119,347	17.51	30.11
Alghero	AHO	Italy	1,365,129	15.48	9.21
Aalborg	AAL	Denmark	1,462,507	45.00	13.5
Montpellier	MPL	France	1,879,963	5.80	5.39
Bremen	BRE	Germany	2,308,338	10.90	8.95
Average				**30.84**	**11.84**

Invoices for en-route charges are issued in € and issued by the Central Route Charges Office (CRCO) of EUROCONTROL in Brussels as a single charge per flight. The revenue is then transferred to the individual countries. Apart from including the costs incurred by DFS, this cost-base also comprises the costs of EUROCONTROL and the aeronautical meteorological service financed from the German federal budget. The charge is a function of MTOM in ton, distance flown in km and a unit rate. This unit rate differs for every country in Europe and is published by EUROCONTROL. The charge is calculated with the formula below:

$$charge = \sqrt{\frac{MTOM}{50}} \cdot \frac{distance\ flown}{100} \cdot unit\ rate$$

Considering the charges in Germany two calculations for air traffic fees have been made. One for an aircraft with an MTOM within the normal category limit of 12,000 lb (5,670 kg) and one for an aircraft with an MTOM within the commuter category limit of 19,000 kb (8,618 kg). The total air traffic fees for a 500 km mission amount to 134.84 € for the former and 169.20 € for the latter. For the purpose of the ELICA operator business case the latter value was applied.

Moreover, depreciation of the battery needs to be calculated. It is assumed that the maximum state of charge is 80 %. Considering a required amount of electrical energy per mission of

78 Trieste: https://triesteairport.it/media/uploads/files/TRS_GenAv_tariffs.pdfRennes: https://www.rennes.aeroport.fr/sites/rennes.aeroport.fr/files/guide_tarifaire_aeronautique_rennes_2020_2.pdf Münster/Osnabrück: https://www.fmo.de/fileadmin/fmo/media/user_upload/pdf/Entgeltordnung_englisch_Aviation_2020.pdf Innsbruck: https://www.innsbruck-airport.com/media/17251/Schedule%20of%20Charges_effective%2001-01-2020.pdf Alghero: https://www.aeroportodialghero.it/public/Aviation/Airport_Fees.pdf Aalborg: https://www.aal.dk/Admin/Public/Download.aspx?file=Files%2fFiles%2fPDF%2fTakst+og+handling%2fAAL-EN-AirportChargesRegulations_2020_v2.pdf Montpellier: https://www.montpellier.aeroport.fr/fileadmin/PROFESSIONNELS/COMPAGNIES/guide-tarifaire-aeronautique-aeroport-montpellier-mediterranee-15-04-2019.pdf Bremen: https://www.bremen-airport.com/uploads/xdownloads/Airport_Charges___Incentive_Scheme_effective_from_1st_of_February_2020.pdf last accessed 31 March 2020

about 215 kWh, about 269 kWh needs to be installed. Cost per kWh is assumed to be 250 € on battery level, lifetime of the battery pack is set to 800 cycles. Assuming an end of live value of about 33 % for the battery, depreciation cost of about 56 € per mission can be calculated.

As it is for now not fully sure, whether there will be an electrical boost during the take-off or a continuous provision of electrical power, cost for energy consumption and battery depreciation are added to mission cost.

Resulting cost per mission (including cost for electrical energy and other mission cost) are calculated to 495 € per paid mission and 309 € per positioning mission (no PAX on board).

Table 9: Air traffic fee calculation[79]

For approach and departure services		
Parameter	**Value**	**Unit**
MTOM example 1	5.670	t
MTOM example 2	8.618	t
Unit rate Germany 2020	126.29	€
Charge example 1	27.52	€
Charge example 2	36.89	€
For en-route services		
Mission distance	500	km
Global unit rate Germany Feb. 2020	63.74	€
Charge example 1	107.32	€
Charge example 2	132.31	€
Total air traffic fees		
Total charge example 1	134.84	€
Total charge example 2	169.20	€

All described values and KPIs can be found in Table 10.

Table 10: ELICA cost assumptions per flight hour and mission as well as KPIs

ELICA net price	6,000,000 €
Depreciation period	21 years
JET-A1 consumption per flight hour	325 l/h
Net price JET-A1 for CAT	0.95 €/l
Electrical energy consumption per mission	215 kWh/mission
Net price per kWh	0.22 €/kWh
Maintenance reserve per flight hour	176.00 €/h
Engine reserve per flight hour	201.65 €/h
Propeller reserve per flight hour	16.00 €/h
Other variable cost per flight hour	45.00 €/h
Variable cost per flight hour	**932.53 €/h**

[79] German Air Traffic Control - https://www.dfs.de/dfs_homepage/en/Services/Charges/ 01.04.2020

Variable cost per flight km	2.49 €/km
Passenger fees per mission	168.72 €/mission
Air traffic fees per mission	169.20 €/mission
Battery depreciation per mission	56.27 €/mission
Other mission cost	23.00 €/mission
Cost per revenue mission	**495.11 €/mission**
Cost per empty mission	**309.14 €/mission**

Besides cost occurring during flight, fixed cost have to be considered for the ELICA operator business case as well. Most important cost driver are staff cost that can be distinguished into salaries, benefits and training cost. Annual salaries are based on expert judgment set to 80,000€ for the chief pilot and 35,000 € for the Co-Pilot. Applying a factor of 1.21 German social benefits are covered. Training cost are taken from the Operation Planning Handbook and set to 16,500 € p.a. Considering 1,650 work hours p.a., 1.8 crews need to be hired per operational ELICA leading to total staff cost of 279,600 € p.a.

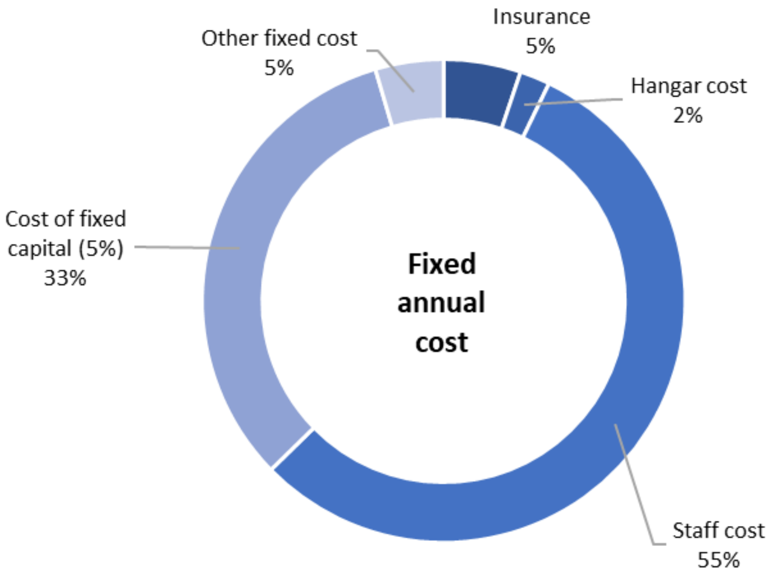

Figure 7-3: Calculated share of annual fixed cost

Again, benchmark values can be derived from the Operation Planning Handbook to estimate further fixed cost. According to those figures, insurance cost are estimated to 26,000 € p.a. and hangar cost to 10,200 € p.a. Furthermore, the cost of fixed capital are valued with 5 % leading to 165,000 € p.a. Other cost are added again with 5 % of the calculated annual fixed cost leading to a total of 504,800 € p.a. The calculated share of annual fixed cost is shown in Figure 7-3. All described values can be found in Table 11.

Table 11: ELICA fixed cost assumptions p.a.

Chief pilot salary (gross, employee)	80,000 €/year
Co-pilot salary (gross, employee)	35,000 €/year
Employer factor for social benefits	1.21
Cost for trainings p.a.	16,500 €/year

Work hours p.a.	1,650 h/year
Staff cost p.a.	**279,604 €/year**
Insurance cost p.a.	26,000 €/year
Hangar cost p.a.	10,200 €/year
Cost of fixed capital (5 %) p.a.	165,000 €/year
Other fixed cost p.a.	24,000 €/year
Fixed cost p.a.	**504,804 €/year**

7.3 Total expenditure, revenues and profits

Table 12 summarises all cost groups resulting from ELICA operation p.a. 10 % are added for general administration and management leading to a total of about 2.6 million €. Assumed revenue per RPK is set (according to the assumption used in the transport model) to 0.53 € resulting in annual revenues per ELICA of about 2.9 million € and a profit of 10.7 % or 313,000 €. Air s.Pace desk research found an average price range for a German first-class train ticket in between 0.45 and 0.60 € per RPK. Analysis of actual flight prices (net incl. fees as calculated here) lead to a price per flight minute of about 2.49 € (cf. Table 16) - ELICA reaches a price per revenue PAX minute of 2.31 € leading to a one-way ticket net-price of 230.55 €.

Table 12: ELICA total expenditure, revenues, and profits

Fixed cost p.a.	504,804 €/year
Variable cost p.a.	1,821,681 €/year
Overhead cost (10 %) p.a.	293,305 €/year
Total expenditure p.a.	**2,619,791 €/year**
Revenue per RPK	**0.53 €**
Net ticket price per PAX (one way)	230.55 €
Revenue per ELICA p.a.	2,933,054 €/year
Profit per ELICA p.a.	**313,264 €/year**

For hourly charter rates of 19-seaters only rough estimates can be found by brokers and websites which collect these. Since they are meant for potential customers usually all surcharges are included in them.[80] The rates are varying strongly depending on both aircraft type and region where the aircraft is operated. The average hourly charter rate for a 19-seater aircraft is 1,830 €. In Table 13 an overview of the aircraft types evaluated can be found and their average price while in Table 15 a more detailed look is given.

Assuming a reduced utilisation rate for charter service of 75 % due to no fixed route services, ELICA could be chartered (net and wet) for 1,368 €.

80 https://aircharterguide.com/CharterBasics.aspx

Table 13: Average hourly charter rates per aircraft type[81]

Aircraft	Average hourly rate [€]
Beechcraft 1900	2,177.85
Viking Air DHC-6-300 Twin Otter	1,486.85
Dornier 228	1,167.95
Embraer EMB-110	2,270.52
Fairchild Swearingen Metroliner	1,605.81
LET410	1,286.63
Average	**1,832.11**

7.4 Analysis and sensitivities

To provide a clearer picture of the main cost drivers of ELICA operation, Figure 7-4 visualises the different cost groups according to their relative share. Main cost driver can be identified as fees, energy cost, staff and overhead expenditure, depreciation and reserves for maintenance and engines.

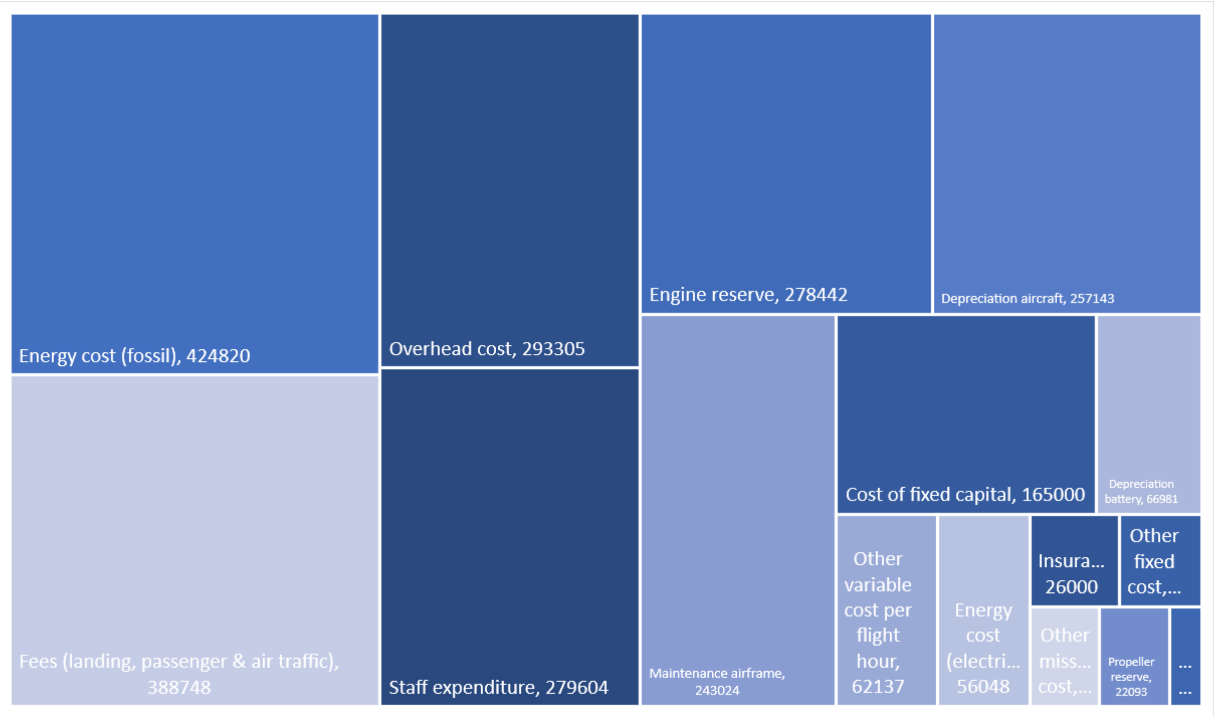

Figure 7-4 ELICA cost positions by relative share to the overall cost

As ELICA is just at the beginning of the design process major decisions that will influence later operation cost still need to be taken. About 58 % of the annual cost can be (strongly) influenced by design choices. Hence, Figure 7-5 provides a reduced picture of those cost groups.

Again, energy cost are one of the biggest positions. They can be influenced by the hourly consumption rate of the engines and the overall efficiency of the powertrain. Depreciation can be seen as a mixed value, as it depends on the aircraft's net price (which is of course derived

[81] Air s.Pace desk research

from production cost) and on the (legally set) depreciation period. In any case focus on cheap production can help to mitigate this position. Reserves for the engines (maintenance and overhaul) as well as for general maintenance are heavy cost drivers as well. They are directly influenced by design decisions that define e.g. the accessibility of maintenance-intensive parts and overall lifetime and maintenance intervals of systems and components. Cost of fixed capital are again depending on the aircraft's net price. Finally, the propeller reserve has to be noted as propeller degradation leads to strong efficiency losses and therefore increases the fuel consumption dramatically.

As no hard data is available for a 19-seater commuter aircraft operation, of course assumptions need to be made. However, some assumptions have a greater influence on the overall result (i.e. profit) than others. To identify those figures, a sensitivity analysis was carried out, assessing the impact of the reference mission distance speed, the load factor or utilisation rate, the ELICA net price and its fuel consumption per hour and the maintenance reserve. With this selection, all important cost groups are considered. Findings for e.g. the maintenance reserve's sensitivity can moreover be directly transferred on other cost positions measured per flight hour.

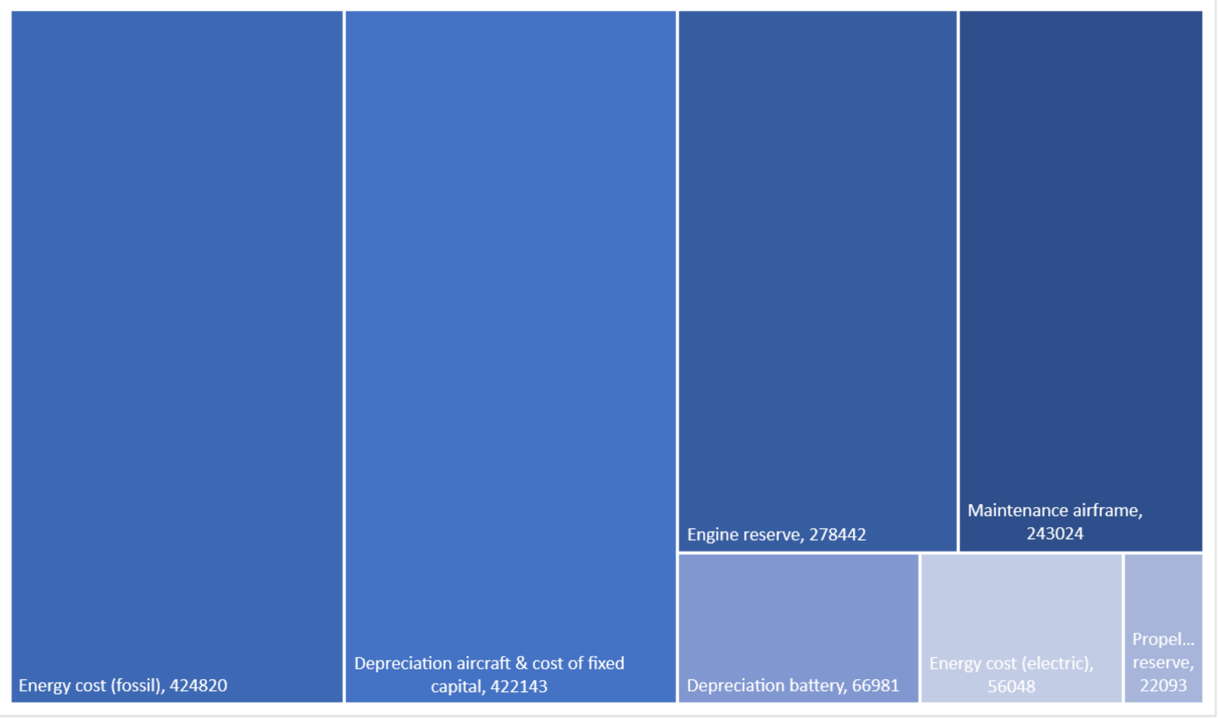

Figure 7-5: ELICA cost positions that can be influenced technically by relative share to the overall technically influenceable cost

The results of the sensitivity analyses that were carried out are shown in Figure 7-6 to Figure 7-11. To summarise the results it can be said that the reference mission distance and speed have a major impact on the profit. If the distance is reduced from 435 km to 350 km, profit reduces by half. If the speed is reduced below 300 km/h losses occur. The same goes for the load factor: If it can be raised from 75 % to 80 %, profits double. Influence of ELICA's net price is of second order for magnitude (about 7,000 € more profit per 100,000 € less aircraft cost). Finally, hourly fuel consumption and maintenance reserve have a direct linear influence on the profit, subsequently an efficiency increase of 1 % leads to 1 % more profit.

In summary, reference mission distance and speed need to be in the focus of future deep dives for a more precise cost assumption. Moreover, ELICA's utilisation rate should be double checked by further examinations and case studies in the future design process.

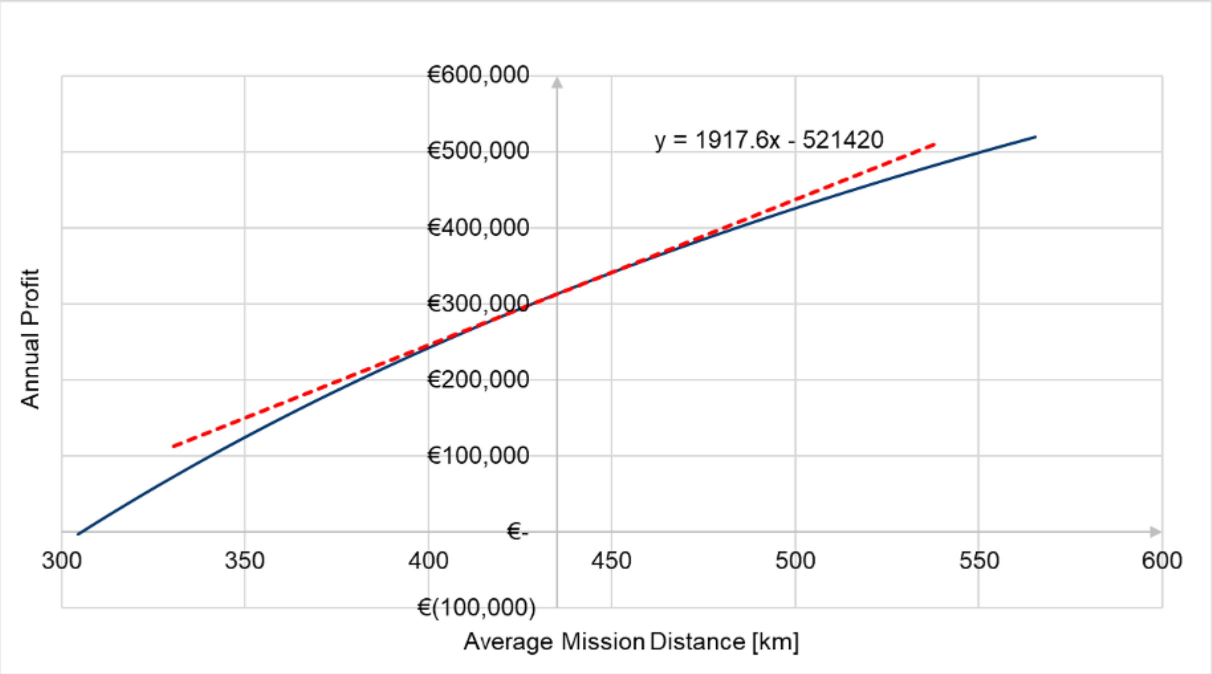

Figure 7-6: Sensitivity analysis for the average mission distance

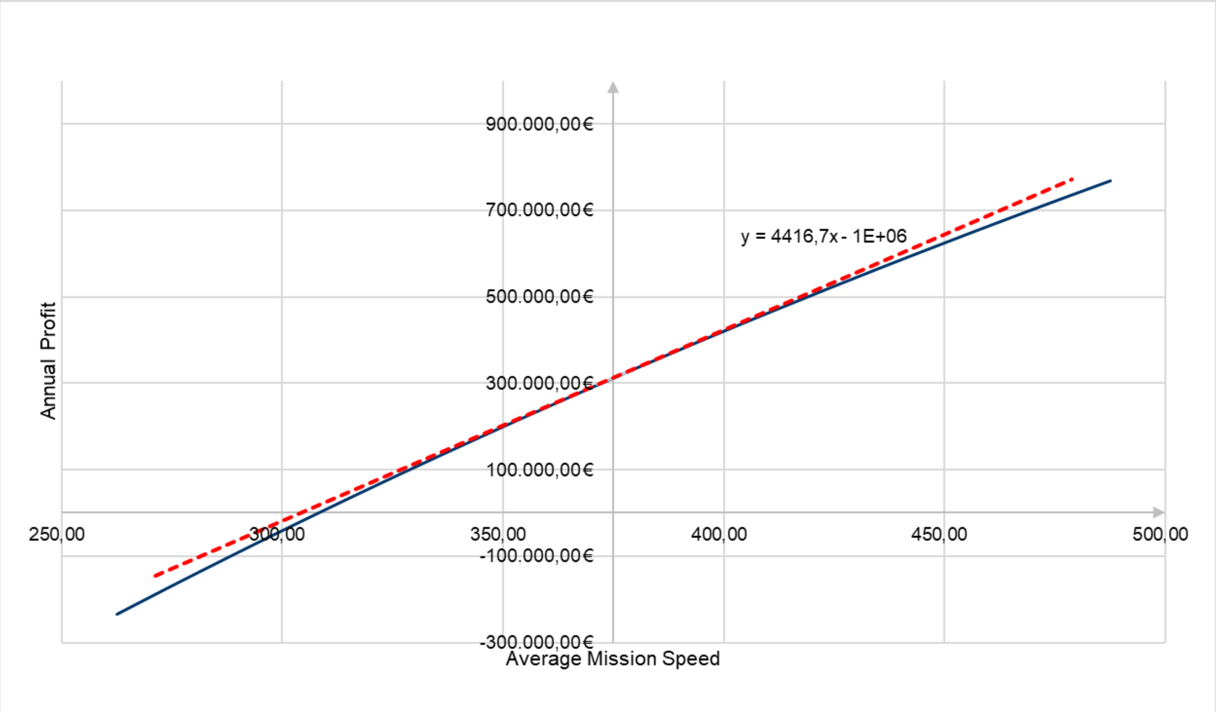

Figure 7-7: Sensitivity analysis for the average mission speed

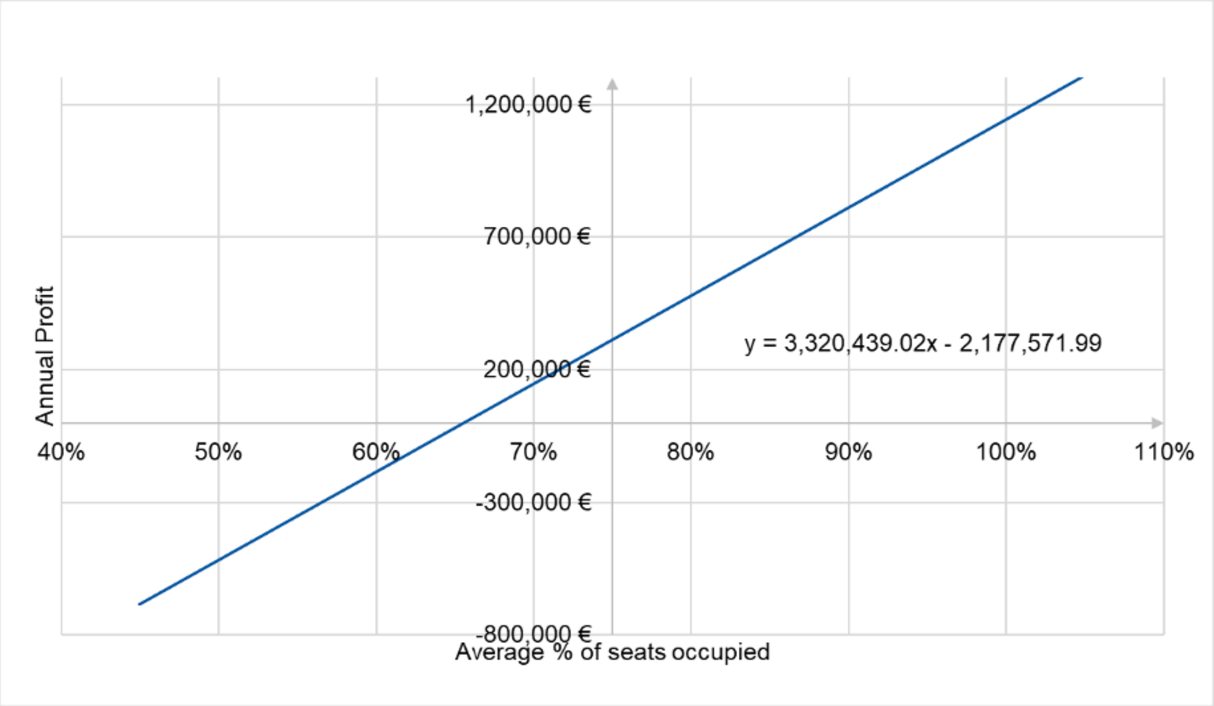

Figure 7-8: Sensitivity analysis for the average load factor

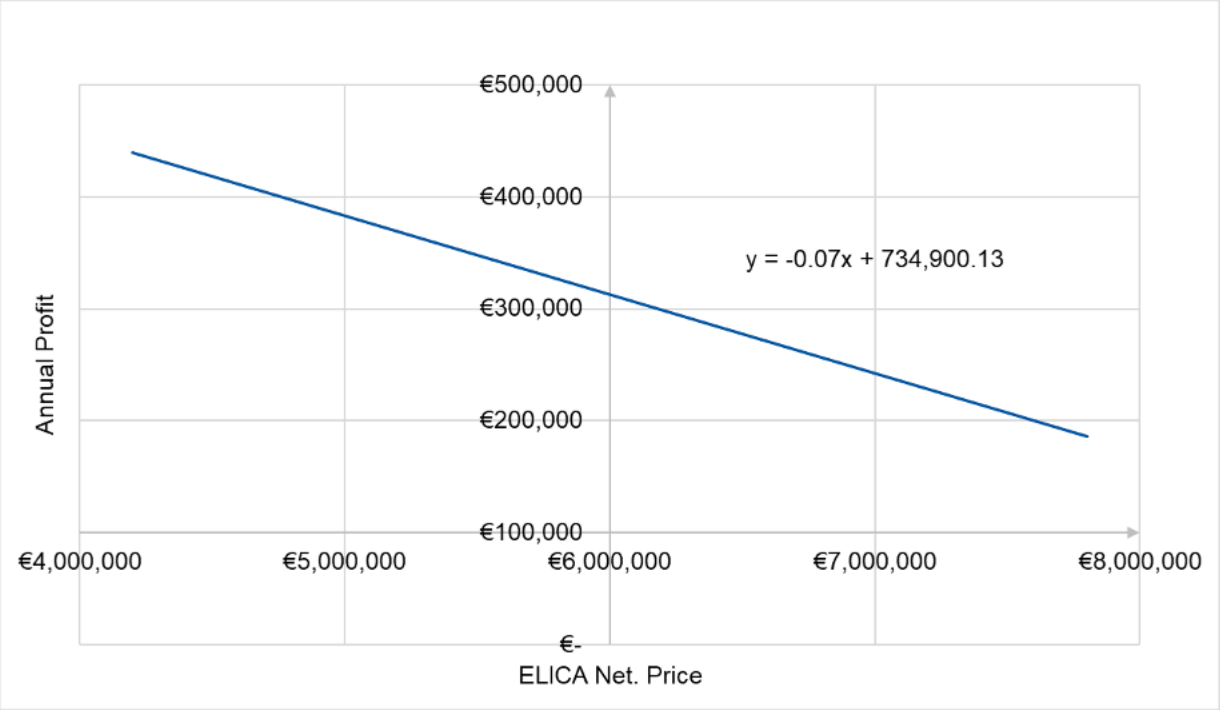

Figure 7-9: Sensitivity analysis for the ELICA net price

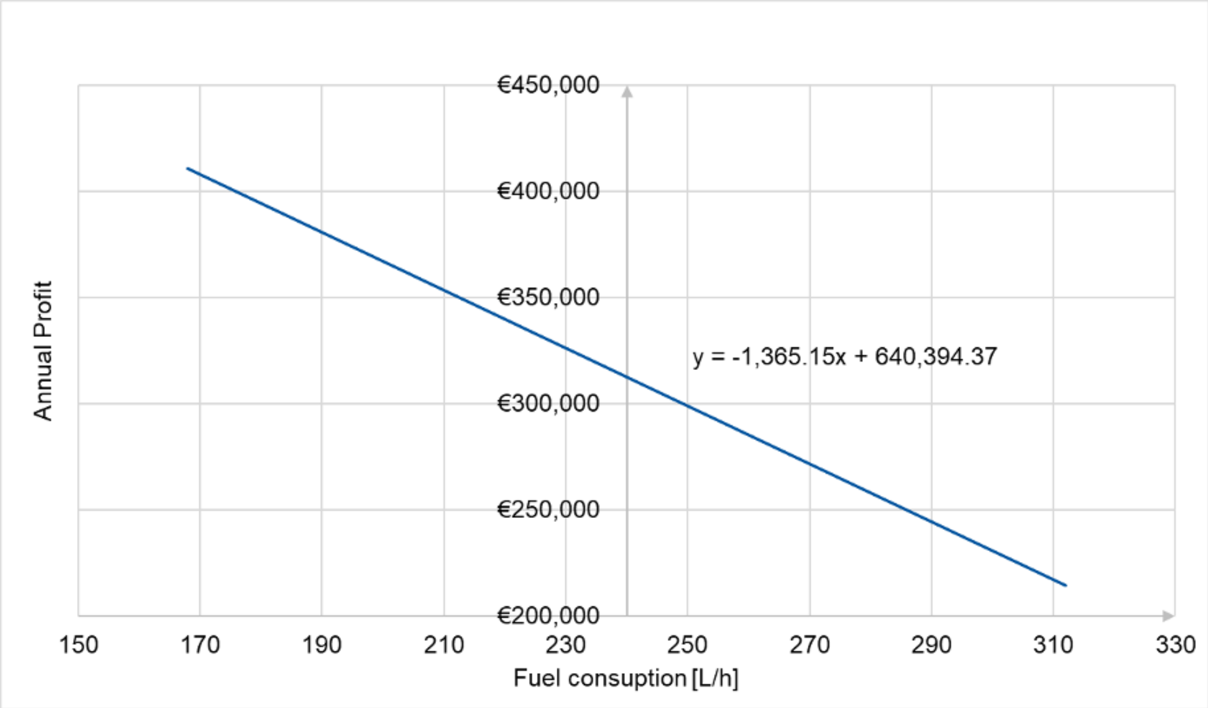

Figure 7-10: Sensitivity analysis for the fuel consumption per hour

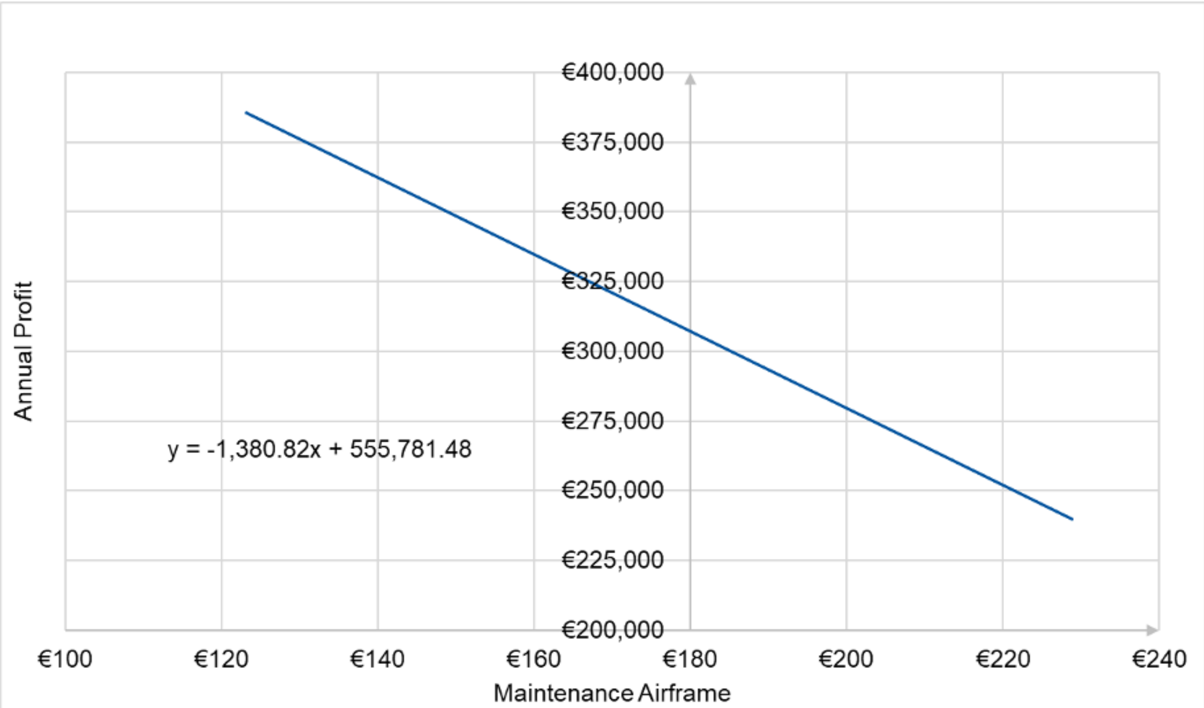

Figure 7-11: Sensitivity analysis for maintenance reserve

7.5 Initial ELICA market sizing

As the assumption of 0.53 € revenue per RPK was validated in section 7.3, findings from the transport study executed in section 6.2 can be used to provide an initial assessment of the market for ELICA in terms of sold aircraft.

Assuming 110 million business trips within Germany (cf. section 5.1) and an ELICA market share of 29,6 % for those trips as well as an average mission distance of 370 km, a total of 12 billion RPK can be derived for the German market. To assure a conservative approach and consider facts that are difficult to be quantified such as airfield availability, density of airline networks, flight fear, etc., 20 % of these RPK are further deducted.

ELICA is predicted to transport about 12,700 PAX p.a. which equals about 5.5 million RPK. Combining these two values, and assuming a range of possible ELICA market shares from 5 to 15 %, between 22 and 65 aircraft can be expected to be operated within the German market. Scaled by GDP[82], rough numbers for the entire European as well as for the US market are calculated, as shown in Table 14.

Table 14: Total ELICA market demand– initial assessment

Region	Assumed market share		
	5 %	10 %	15 %
German fleet size	22	43	65
European fleet size	103	206	309
US fleet size	134	268	401
Total fleet size	**237**	**474**	**710**

Depending on the realised market share, a total market demand between 240 and 710 aircraft is predicted. Comparing these estimations with hard sales as presented in Table 2, ELICA would range in the same class as the PZL M28 Skytruck (256 sold aircraft) or even reach up to the Beechcraft 1900 (692 sold aircraft) or the Fairchild Swearingen Metro (700 sold aircraft).

Average market share for all discussed 19-seater commuter aircraft (cf. Table 2) is 9 %. While the PZL M28 Skytruck realised a market share of about 5 %, the Beechcraft 1900 and Fairchild Swearingen Metro of about 13 %.

Moreover, it has to be added that these figures focus on business transport. Further upside potential can be assumed by ‘normal’ passenger service (e.g. ‘island hopping’), air cargo services (as depicted in section 5.2) or special missions (e.g. military).

Figure 7-12 showcases a possible production ramp-up for ELICA. Key assumptions are that the entry into service (EIS) occurs firstly in Europe and one year later in the US. Four years after market entry, a stable production rate will be reached and the estimated overall market demand will be satisfied within ten years. Average stable production rates sum up to 57 aircraft p.a. for the European and US market by assuming a market share of 10 %. If market share is only 5 %, a stable production rate of 28 aircraft is predicted and by 15 %, a yearly production rate of 85 aircraft is estimated.

82 https://de.statista.com/statistik/daten/studie/1251/umfrage/entwicklung-des-bruttoinlandsprodukts-seit-dem-jahr-1991/ ; https://de.statista.com/themen/2280/bruttoinlandsprodukt-bip-in-eu-und-euro-zone/ ; https://de.statista.com/statistik/daten/studie/14418/umfrage/bruttoinlandsprodukt-in-den-usa/

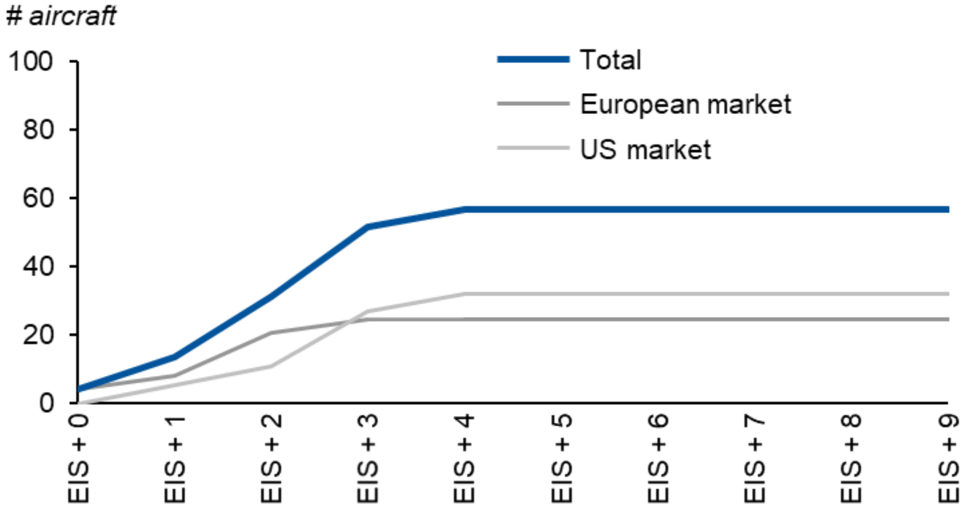

Figure 7-12: Initial sizing of the annual production rate for an assumed ELICA market share of 10 %

7.6 Interim conclusion

In summary, a positive business case for ELICA from an operator perspective is feasible with a return on sales of more than 11 %. Annual flight hours are estimated at 1,380 hours p.a. with a share of paid missions of 75 % and a reference mission with a flight distance of 435 km and an average speed of 375 km/h. Variable cost per flight hour are assessed to be 930 €, average revenue mission cost are 495 €. Fixed annual cost sum up to 505,000 €. Assuming a price per RPK of 0.53 € (comparable to German first-class ticket prices), an annual revenue of 2.9 million € is predicted. Average ticket cost are in line with researched benchmark prices for 19-seater commuter aircraft.

Main cost driver that can be influenced by design choices are energy cost, maintenance efforts (especially for overall maintenance and the engines), and capital cost (depreciation and fixed capital cost). Sensitivity analysis showcased a major influence of the above discussed cost positions.

Initial market sizing was done for different market shares based on the results of the transport study executed in section 6. Results show a total market demand for Europe and the USA between 240 (5 % market share) to 710 aircraft (15 market share) for RAM with a focus on business customers. Stable annual production rates appear to be around 57 aircraft (Europe plus US) p.a.

Overall business development for ELICA has identified quite positive signals for the further development of ELICA. Key assumptions and cost estimations need to be re-assessed on a regular basis in close cooperation with the technical design partners of ELICA to assure a consistent proceeding for the overall project.

7.7 Business case appendix

Table 15: hourly charter rates. Different offers[83]

Model	Passenger (PAX) / Cargo configuration	Charter company	Country	Region	Hourly rate [€]
B1900	PAX	North Cariboo Air	Canada	North America	1,128.83
B1900	Cargo	Ameriflight	USA	North America	1,979.89
B1900	Cargo	Ameriflight	USA	North America	2,102.50
B1900	Both	Searca S.A.	Colombia	South America	1,362.31
B1900	Cargo	Alpine Aviation	Cargo	North America	1,907.23
B1900	Cargo	Freight Runners Express	Cargo	North America	1,687.45
B1900	PAX	Flight Link Air Charters	Tanzania	Africa	1,634.77
B1900C	PAX	Evojets	USA	North America	2,225.11
B1900D	PAX	unspecified	unspecified	unspecified	3,178.72
B1900D	PAX	PrivateFly	USA	North America	3,259.55
B1900D	PAX	Aero Affaires	France	Europe	3,490.00
DHC-6-300	PAX	Air Tindi	Canada	North America	1,032.07
DHC-6-300	PAX	Grand Canyon airlines	USA	North America	1,702.89
DHC-6-300	PAX	ARM Aviacion	Guatemala	South America	1,725.59
Do 228	Cargo	Bighorn Airways	USA	North America	1,167.95
EMB-110	PAX	Aberdair	Kenya	Africa	2,270.52
Metroliner	Cargo	Ameriflight	USA	North America	1,761.92
Metroliner	Cargo	Pak West Airlines	USA	North America	1,089.85
Metroliner	PAX	Berry Aviation	USA	North America	1,271.49
Metroliner	PAX	Aero Affaires	France	Europe	2,300.00
LET410	Both	Searca S.A.	Colombia	South America	817.39
LET410	PAX	Aerolineas SOSA	Honduras	South America	862.80
LET410 UVP-E20	PAX	Silver Air	Czech Republic	Europe	2,179.70
Average charter rate for flights in July 2020 (researched in March 2020)					**1,832.11**

83 Air s.Pace desk research

Table 16: Air fares for 19-seaters[83]

From	To	Airline	Aircraft Type	Duration [min]	Distance [km]	Country	Full Price	Bare Price	Fees	Taxes	Full Price /min	Full Price /km	Bare Price /min	Net Price + Fees /min	Bare Price /km	Net Price + Fees /km
Halifax (YHZ)	Charlottetown (YYG)	Exploits Valley Air	B1900D	42	1030	Canada	314.84	243.00	30.76	41.08	3.75	0.15	2.89	3.26	0.12	0.13
King Island (KNS)	Melbourne (MEB)	Sharp Airline	Metroliner	45	255	Australia	166.85	151.68	15.17	0.00	1.85	0.33	1.69	1.85	0.30	0.33
Thunder Bay (KNS)	Sudbury (YSB)	Bearskin Airline	Metroliner	70	664	Canada	145.23	99.93	28.45	16.70	1.04	0.11	0.71	0.92	0.08	0.10
Winnipeg (YWG)	Thompson (YTH)	Perimeter Aviation	Metroliner	120	657	Canada	601.74	490.94	82.13	28.67	2.51	0.46	2.05	2.39	0.37	0.44
Guernsey (GCI)	Alderney (ACI)	Aurigny	Do 228	20	41	UK	110.14	110.14	N/A	N/A	2.75	1.34	2.75	2.75	1.34	1.34
Alderney (ACI)	Southampton (SOU)	Aurigny	Do 228	40	151	UK	240.13	240.13	N/A	N/A	3.00	0.80	3.00	3.00	0.80	0.80
Münster/ Osnabrück (FMO)	Stuttgart (STR)	AIS Airlines	Jetstream 32	80	400	Germany	220.00	146.80	21.36	53.84	1.38	0.28	0.92	1.05	0.18	0.21
Fort Smith (YSM)	Yellowknife (YZF)	Northwestern Air	Jetstream 32	55	304	Canada	613.34	500.32	61.89	44.36	5.58	1.01	4.55	5.11	0.82	0.92
Paris Orly (ORY)	Le Puy (LPY)	Twin Jet	B1900D	65	420	France	391.75	301	41.36	49.39	3.01	0.47	2.32	2.63	0.36	0.41
Toulouse (TLS)	Metz Nancy (ETZ)	Twin Jet	B1900D	100	703	France	431.03	280	100.07	50.96	2.16	0.31	1.40	1.90	0.20	0.27
Average							**323.50**	**256.39**	**38.12**	**28.50**	**2.70**	**0.52**	**2.23**	**2.49**	**0.46**	**0.49**

8 Conclusion

The overall question that guides this economic feasibility study for ELICA is to assess whether it is time for a new 19-seater commuter aircraft design, powered both by turboprop and electrical engines.

First, the turboprop aircraft market was analysed that is overall developing positively with about 560 aircraft sold p.a. worldwide (CAGR of 6.3 %) with most of them produced in the US. In total, about 5,500 19-seater commuter aircraft types were sold globally, spread across 11 different aircraft models. Most successful models were the Czech LET410 with 1,170 delivered units and the DHC-6 Twin Otter with 960 aircraft.

Cessna is currently developing the SkyCourier with FedEx as an anchor customer. This can be regarded as a positive sign for this market segment, as currently only three out of 11 aircraft models are in production. 19-seater commuter aircraft experienced their greatest usage in the 1990s with more than 3,200 aircraft in operation – currently, this figure dropped to 2,300. About 70 % of the civil missions focussed on passenger transport (most of it ‘island hopping’) and about 15 % on air cargo. North America is by far the most relevant market for such aircraft. A large share of 19-seaters is used for military purposes (e.g. for search and rescue or surveillance missions).

Two promising new market segments are introduced: RAM with average mission distances between 100 and 400 km to support the reduction of overall travel times by direct point-to-point connections of regions without airport access by exploiting the dense network of airfields in Europe and the US. This market is not only scientifically backed-up but also addressed by start-ups such as the German e.SAT GmbH.

The second new market segment is thin-haul air cargo services which is heavily pushed by Amazon to further reduce delivery times. Currently, also small aircraft (below 80 seats) are operated for cargo transports and the market is expected to grow significantly within the next twenty years with a CAGR of 4.2 %. Further cost saving potentials due to the hybridisation are assessed positively and with Scotland and Norway two initial markets are identified that actively support the introduction of electric aircraft. A case study for Cirrus Aircraft showcases the successful market entry of a new player within General Aviation.

A dense network of airfields covering Europe and the US is ready for use and can help to realise RAM services as well as thin-haul air cargo. About 99 % of the US population lives within 30 km distance to an ELICA-feasible airfield. Europe is with a respective share of 77 % ready for this new mode of transport as well. A transport simulation was executed for the German market and found that ELICA-services could reach a market share within business trips of about 30 %, leading to an average mission distance of 370 km while assuming an average cruise speed of 375 km/h and a price per RPK of 0.53 € (fully in line with current pricings).

Moreover, a business case for ELICA from an operator perspective is executed. Assuming a utilisation rate of 75 %, about 1,380 flight hours will be done p.a. Cost are assessed to be about 930 € per flight hour, 495 € per revenue mission, and 505,000 € of annual fixed cost – assuming a hybridisation of 15 %. A total annual expenditure of about 2.6 million € is met by revenues of about 2.9 million € leading to a profit of 313,000 € (10.7 %). All derived performance measures are in line with current benchmark figures. Strongest cost drivers that can be influenced by the design are of course energy consumption, but also maintenance efforts for the overall aircraft and the engines.

An initial and conservative market assessment postulates a market demand for Europe and the US between 240 and 710 aircraft – for RAM purposes only. The annual production rate to satisfy this market is assessed to 28 to 85 aircraft p.a. Baseline is an ELICA market share of between 5 to 15 %.

As a whole the economic feasibility study supports a new design of an electro-hybrid 19-seater commuter aircraft as new market segments can be expected to open up and a positive business case can be provided. Hence it is time for a new 19-seater commuter aircraft design.