Potential network planning for electric aircraft

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Abstract

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This thesis aims to give an overview of how electric aircraft can be included into the airlines' current networks, what business models could suit this innovation, along with what possible networks, routes and markets could be ready to welcome this new frontier of sustainable aviation.

Driven by the pressure of the worsening climate situation, the aviation industry is striving to cut its emissions as much as possible, with zero as a final goal. Among the different innovations currently under development, electric aircraft represent an opportunity and a promising solution.

The first commercial flights operated by electric aircraft are believed to start in 3-4 years, with two manufacturers currently prototyping their models, expected to get into the market in the near future: Heart Aerospace (Sweden), with its *ES-30*, and Eviation (Israel/USA), with *Alice*. As of 2022, there is no research touching the operational side of electric aviation, as the sector is still very young.

The theoretical framework of this study covers the current research about electric aircraft from a business perspective, analyzing the state of the art, the developments, the benefits and the challenges, and it reviews the theories of airline network planning, with elements of network structure, design and scheduling, along with a focus on regional aviation.

The result is a framework presenting the characteristics that a market should have in order to be properly served by electric aircraft; an evaluation of some of the current customers is also made. Then, the elements of the framework are practically applied in some case studies, and four examples of implementation into the Nordic countries have been designed by the author.

Key words
Electric Aircraft, Electric Aviation, Network Planning

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0 List of abbreviations

A/C	Aircraft	kts	Knots
ALF	Alta Airport, Norway	LCC	Low-Cost Carrier
ARN	Stockholm-Arlanda Airport, Sweden	MHQ	Mariehamn Airport, Finland
arr	Arrival	mi	Miles
DEL	Delhi-Indira Gandhi Airport, India	nmi	Nautical Miles
dep	Departure	POR	Pori Airport, Finland
EAS	Essential Air Service	PSO	Public Service Obligation
ENF	Enontekiö Airport, Finland	O&D	Origin and Destination market
EU	European Union	OUL	Oulu Airport, Finland
FSNC	Full-Service Network Carrier	RIX	Riga Airport. Latvia
HEL	Helsinki-Vantaa Airport, Finland	RVN	Rovaniemi Airport, Finland
IVL	Ivalo Airport, Finland	SAF	Sustainable Aviation Fuel
JOE	Joensuu Airport, Finland	STOL	Short Take Off and Landing
JFK	New York J.F. Kennedy Airport, USA	SVL	Savonlinna Airport, Finland
JYV	Jyväskylä Airport, Finland	TAY	Tartu Airport, Estonia
KAJ	Kajaani Airport, Finland	TKU	Turku Airport, Finland
KAO	Kuusamo Airport, Finland	TLL	Tallinn Airport, Finland
KEM	Kemi-Tornio Airport, Finland	TMP	Tampere Airport, Finland
km	Kilometers	TOS	Tromso Airport, Norway
km/h	Kilometers per hour	UN	United Nations
KOK	Kokkola-Pietarsaari Airport, Finland	USA	United States of America
KRN	Kiruna Airport, Finland	VAA	Vaasa Airport, Finland

1 Introduction

This chapter presents a background to the study, along with an overture on main topics and concepts of this research, circumscribing it on the current business environment, and it presents the processes and final objectives of the study.

1.1 Background

In order to contain the increasingly serious threat of climate change, international action and commitment is required: into this spirit, in 2015, the United Nations (UN) ratified a protocol, named “Paris Agreement”, whose main objective is “holding the increase in the global average temperature to well below 2°C […] and pursuing efforts to limit the temperature increase to 1.5°C, recognizing that this would significantly reduce the risks and impacts of climate change” (UN 2015). With the Paris Agreement, all the member states of the UN commit to support a major shift towards sustainability among all industries.

In order to achieve such goal, with the support of national and international governmental bodies, the worldwide joint effort of individuals, industries and all economic sectors is needed to cut emissions as much as possible. The aviation industry, being responsible for a high amount of global carbon emissions, is one of the players striving to reduce its ecological footprint: according to a study made by the Air Transport Action Group (ATAG, 2020), the global aviation industry produces 915 million tons of carbon dioxide (CO_2), accounting for around 2,1% of all human-induced emissions.

In Europe, the European Commission, on its strategy for Smart and Sustainable Mobility (2020), targets to increase “the uptake of zero-emission vehicles, vessels and airplanes, renewable & low-carbon fuels and related infrastructure” and to create zero-emission airports and ports by 2035, encouraging all the EU members to embrace sustainability as a key factor for economic growth.

Driven by the common, worldwide effort to significantly reduce emissions, all the stakeholders within the aviation industry are searching for innovative, sustainable solutions for both the short- and long-term future (Mestvedthagen 2022). Among the first steps taken, there is the growing utilization of Sustainable Aviation Fuel (SAF) as a direct replacement for fossil jet fuel, already reducing greenhouse gas emissions by up to 80% compared to fossil jet fuel according to the Finnish oil refiner Neste, which is one of the major producers of SAF.

Research and innovation are moving further, and they are aiming to drastically cut emissions to zero, or at least as close as possible to it. While most of the sustainable alternatives currently offered in the market are limited to just reduce emissions, for example manufacturing quieter, less fuel-consuming aircraft, several projects within the aviation industry are committed to cut completely fossil emissions: this is the case of electric aviation.

1.2 Electric aviation as a potential reality

Electric and hybrid-electric propulsion is increasingly becoming a solid reality of mobility technologies in all fields of transportation, with aviation not being an exception. Thapa et al. (2020) define electric aviation as “a reality on its way”, with a long story on its back, with the first experiments dating as back as the 1970s. The increasing research and the worsening climate situation are just speeding up the process of turning the current state of electric aircraft, now limited to small projects and prototypes, into a potential reality for commercial aviation.

According to the current state of the art, electric aviation could become an integrated part of airlines’ operations by the late 2020s; and the process of route planning, including evaluation of potential markets and routes, usually takes place between 1 and 4 years before departure. Therefore, 2022-2023 can be a right time for airlines to start drafting how business operations of electric aircraft could be shaped and implemented into their core businesses, especially thanks to the growing interest manifested by an always growing numbers of stakeholders in the industry.

1.3 Objectives of the research

The objective of this study is to conceive how potential air route networks served by electric airplanes can be designed and structured based on the current developments, what business models could be considered suitable for those networks and what markets could introduce this innovation.

This study wants to be a forerunner of the business operations of the future, hoping to perhaps trigger further research on business feasibility and strategies for the implementation of electric aviation into airlines’ current operations.

This study will first review what is currently known about electric aviation, with a special focus on two manufacturers whose projects are believed to become reality in a few years, assessing what are the main strengths, the limitations and the opportunities; then, an overview of airline network planning will be given, including elements of network design and scheduling, with special attention to regional aviation. Next, the knowledge of the two topics will be combined, resulting into a general framework which will then be supported by short case studies of potential airline networks.

1.4 Key concepts

Network planning is the result of the carrier's business strategy and geographical scope, and it is usually linked to the business model adopted by an airline. Network planning can be divided into two distinct phases: design and scheduling (Holloway 2008a).

Electric aviation is one of the latest innovations in the aviation industry, currently undergoing intense research and prototyping, in order to provide a zero-emissions, more sustainable alternative to commercial aviation. With several projects under development all over the world, the first revenue flights operated by electric-powered aircraft are expected to start between 2026 and 2028, with Scandinavian countries and United States announced as the first possible markets.
Currently, the research on electric aviation consists of the implementation of hybrid aircraft (supported by both fuel and electricity) and all-electric aircraft, both powered by batteries.

2 Electric aviation, electric aircraft: the frontier of sustainable flights

This chapter gives an overview of what has been researched and discovered so far about the development of electric aircraft from a business perspective, including a short historical development, the state of the art and general information useful for the research. This review is conducted through peer-reviewed articles, along with the use of official websites from the stakeholders involved in the development of this innovation, which provide at the moment the most complete insights.

2.1 History and development

As mentioned in Chapter 1.2, electric flying is not a completely new technology: the first attempts of get to the skies with battery-powered models dates back to around 1970: since then, the research and the testing on electric aircraft has been quite meagre, and usually limited to small, one-seat recreational planes, mostly powered by solar light (Thapa et al 2020).

During the 2010s, several projects for commercial airliners have been theorized: they are all, as of 2022, under research and development, or completely abandoned. These are two examples:

- The British company Wright Electric is working on retrofitting older British Aerospatiale Bae146 jets into zero-emission planes powered by hydrogen cells, with the Low-Cost Carriers easyJet (United Kingdom) and Viva Aerobus (Mexico) as potential customers. These aircrafts are expected, on a first stage, to cover routes with a flight time under one hour (Wright Electric 2022).
- In 2010, the European manufacturer Airbus has started its journey towards decarbonized aviation. Between 2010 and 2019, Airbus has manufactured and prototyped mostly small electric-powered models, such as helicopters and race planes. Between 2017 and 2020, the company has worked on a larger project for a commercial airplane, called E-Fan X. The project has been set aside in April 2020; however, its development has brought rich insights to Airbus towards its continuous development in the field (Vittadini 2020).

Since the late 2010s, with the pressure given by worsening climate change situation, the development towards zero-emission aviation has significantly risen, with a growing number of stakeholders within the industry expressing their interest in sustainable innovation. Under these circumstances, the two leading manufacturers of electric aircraft (see Chapter 2.2) were founded in these years.

As of 2022, the start of commercial flights for electric aircraft looks closer, with some prototypes already approaching certifications from aviation regulators; at the same time, some countries are making plans to completely decarbonize domestic air travel: in the case of Norway, the objective is to electrify its whole domestic network of the country by 2040 (Avinor).

2.2 Current manufacturers and prototypes

Two main manufacturers are, at the moment, leading in the industry for their extensive work and research in the field of electric aviation: Heart Aerospace (Sweden) and Eviation (Israel/USA). More technical data about the two prototypes can be found in Chapter 5.1.

2.2.1 Heart Aerospace, ES-19 and ES-30

Heart Aerospace is a start-up company based in Gothenburg, Sweden, and founded in 2018 by the Swedish entrepreneur Anders Forslund, also Heart’s Chief Executive Officer. The company’s mission is to “to create the world’s greenest, most affordable and most accessible form of transport” (Heart Aerospace 2022a) and it counts, as of July 2022, around 120 employees. Their prototype for commercial aviation, named ***ES-19***, as of Summer 2022, is undergoing testing and applications to certify the aircraft internationally.

The project of *ES-19* would be a 19-seat aircraft powered by an electric propulsion system with a STOL (Short Take-Off and Landing) certification, meaning that it will be able to operate on runways as short as 750 meters, enabling greater opportunities for regional airports and small aerodromes closer to city centers (Heart Aerospace 2022b).

In September 2022, Heart Aerospace has announced some major changes into their projects. The prototype of ES-19 has evolved into a completely new airplane, named ES-30. The new prototype will be able to fly up to 200 kilometers powered by batteries, with additional 200km guaranteed by a reserve of fuel, being able to cut emissions by half on routes under 400km. Along with this new announcement, Heart Aerospace confirmed new future customers of the aircraft, including, for example, Air Canada and Scandinavian Airlines, along with new investors and collaborators, such as the Swedish manufacturer SAAB.

2.2.2 Eviation, Alice

Eviation was founded in 2015 in Tel Aviv, Israel, by two Israeli entrepreneurs with a background in physics, green energy and the military. The first electric prototype designed by Eviation, named Orca, has been displayed in 2017 at the Paris Air Show.

The leading project for commercial aviation, called ***Alice***, has been unveiled for the first time in 2019, with the manufacturing assembly starting in 2021 in the United States. Alice is fully electric-powered aircraft, designed in three versions: Commuter (9-seat, suited for commercial flights), Executive (for general aviation), and also in a freighter variant (Eviation 2022a).

2.3 Expected timelines and certifications

While the tests are underway, Heart Aerospace is predicting to get all the aircraft certifications needed on the third quarter of 2026, expecting to enter into service by the end of the same year. In June 2022, Heart Aerospace announced it has changed the certification basis for its ES-19 model, meaning that the market accessible by the aircraft will be significantly increased. Forslund, in a press release, stated “The *ES-19* started small as a niche product for the Nordic market, but it turns out it has a much more global appeal. The response has been beyond expectations. To reach a broader market we are now taking a big step forward” (Heart Aerospace 2022c).

Eviation, on the other hand, has not yet planned a launch date for *Alice*, but the company expects to get the full United States’ Federal Aviation Administration (FAA) certifications by 2025, following an entry in commercial service in around 2027, with several interested customers mostly in the United States. In September 2022, *Alice* made its first test flight, flying for eight minutes at an altitude of 3500 feet (around 1070 meters). According to Gregory Davis, Eviation’s Chief Executive Officer, the flight “made aviation history. It’s the first time an electric aircraft of this scale has flown” (Bardsley 2022).

2.4 Potential customers

Several airlines are getting interested in acquiring electric aircraft to add to their fleet as soon as these aircraft will be able to enter service.

One of the first airlines to express deep interest into electric aircraft has been the Norwegian regional carrier Wideroe (WF/WIF): in 2019, the airline has started a collaboration with the engine manufacturer Rolls-Royce, in order to develop a zero-emission plane able to replace its current regional, fossil-fueled fleet, with the priority given to Norway’s routes from and to STOL airports. Wideroe is also urging governments and authorities to shape the policies of the future regarding zero-emission aviation, for example asking to accommodate the transition to zero-emissions air travel with physical and financial support (Wideroe).

In March 2021, the Finnish flag carrier Finnair (AY/FIN) has signed a letter of interest with Heart Aerospace, with the intention of buying up to 20 ES-19 to cover, at least on a first stage, the shorter routes of its regional network within Finland and the Baltic Sea. This collaboration follows the joint effort of several aviation stakeholders within the Nordic countries into the Nordic Network for Electric Aviation, which has seen governments, airlines and companies collaborate on new innovative projects to help develop sustainable ways to travel (Finnair 2021).

In July 2021, Chicago-based United Airlines (UA/UAL) and its regional airline partner Mesa Airlines have signed an agreement with Heart Aerospace to acquire up to 100 ES-19 planes to serve its regional routes from as early as 2026. UAV (United Airlines Venture), a parent company of UA, focusing on innovative sustainability concepts towards a carbon-neutral airline, decided to invest on Heart’s project. (United 2021).

On 15th September 2022, when announcing some major changes to the project, Heart Aerospace has announced a number of additional carriers interested in buying some ES-30 aircraft, including Air Canada, Braathens Regional Airlines (TF/BRA), Scandinavian Airlines (SK/SAS), Icelandair (FI/ICE), Sounds Air (S8/SDA). Overall, these carriers have planned to order altogether 96 aircraft, with their Letters Of Intent (LOI).

In November 2022, Eviation announced that the order book for Alice has surpassed the value of 2 billion dollars, counting around 300 orders, with customers including the American regional airline Cape Air and the German Air operator Evia Aero (Eviation 2022b).

2.5 Financial viability of electric aviation

Schafer et al. (2019) provide a prospect of a possible cost structure for electric aircraft. While the major concern is given by the potentially high price of batteries used to power the airplanes, several other factors would contribute to considerable savings: for example, electric aircraft would not need additional fuel systems, as, for instance, they do not need an Auxiliary Power Unit (APU) to generate electricity. Also, with relatively simpler motor systems, maintenance costs could also be cut. Moreover, the study argues that in a first stage policies supporting low-carbon electricity (e.g. a carbon tax) may be a central requirement for letting electric aircraft penetrate the market more easily. Hospodka et al. (2020) add that operational costs for electric aircraft would considerably vary also in relation to the prices of electricity and the energy production mix of a country.

Medeiros & Monzu (2020) have tried to evaluate the possible costs of operating a 19-seater aircraft powered by lithium-Ion batteries. The results of their study demonstrate that electric aviation “could offer a very interesting approach” to drastically reduce the operating costs of the airline, at least for shorter air routes, proving Heart Aerospace’s project economically viable in regional markets.

Another matter which might affect the economic feasibility of electric aviation is outlined by Schwab et al (2021), who assert that airports would need to implement an appropriate infrastructure to support such operations. Factors impacting airport operations include, among others, electrical needs, current power capabilities, and density of the expected demand. The authors wish for further research and development supporting the electrification of aviation, including more integration within the stakeholders (mainly airlines and airports).

2.6 Markets and competition

The two electric aircraft manufacturers above mentioned both express the intention of utilizing their aircraft on short, regional routes. According to Nõmmik and Antov (2020), the efficiency of regional routes and small, peripherical airports, especially in Europe, is compromised by the growth in number of seats in narrow-body aircraft: this means that, while airlines focus their fleets on the introduction of larger aircraft, they do not have an appropriate fleet which could support the low demand generated by secondary areas of Europe, leaving some remote regions unserved or poorly connected. Redondi et al. (2013) estimate that airports with a traffic of less than one million passengers account for around two thirds of all European airports, and their closing would result in a loss of connectivity for a large percentage of the population. Countries like Finland, Sweden and Norway would find themselves with around a fifth of their populations experiencing 20% longer average travel times.

On short distances and regional areas, especially on Europe, air transport faces a strong competition also from other means of transport. Abbate et al (2016) study the case of the connections between Milan and Rome (Italy), where the fierce competition between airplanes and high-speed trains has brought an asymmetrical reaction to pricing and connectivity strategies, which later resulted in a prevalence of railway. Also, in an attempt to reduce carbon emissions, several countries are banning shorter regional flights in favor of train connections: one example is France, where in April 2022 the country’s Parliament decided to cancel all domestic routes which could be instead covered by train in less than 2,5 hours (Ahlgren 2022).

2.7 SWOT Analysis

In order to complete this overview about electric aviation and further understand internal and external factors which might be encountered, a SWOT Analysis has been conducted. This framework is a common business tool for strategic analysis, summarizing and assessing several aspects impacting positively or negatively the matter taken into account: internal factors (Strengths, Weaknesses) and external factors (Opportunities, Threats) (Helms & Nixon 2010).

STRENGTHS

- Sustainable alternative to fuel-powered aircraft
- Potential cost saving (e.g. APU)
- Easier and more affordable maintenance costs
- Emission reduction (as close as possible to zero)
- Noise reduction
- Reduced take-off distances (STOL)

WEAKNESSES

- Airplanes' short range (at least in a first stage)
- Cost of batteries might be high
- Need for new, specific infrastructure in airports
- Need for additional electricity supply

OPPORTUNITIES

- Drastically reduce (if not eliminate completely) CO_2 emissions on regional routes
- Give a considerable contribution towards a greener industry
- Generate and stimulate demand on lower-yield routes
- Lead growth in regional markets and secondary airports

THREATS

- Fluctuation of electricity prices
- Competitiveness of high-speed trains in European market
- Possible issues and delays regarding certifications and prototypes
- Lack of infrastructure integration (airport and airline)

3 Theoretical framework

This chapter provides a theoretical framework regarding airline network management, with definitions and processes used in any network strategies conducted by any carriers. This framework supports the study with a solid conceptual background, and it analyzes how airline networks are structured, what connections exist between networks and business models, with a focus on the characteristics of regional networks; lastly, some elements of scheduling will be touched.

3.1 Definitions of network planning

According to Holloway (2008a), an airline's network is the concrete result of an airline's business strategy and geographical scope. It is shaped by the business model adopted by an airline and by the nature and the characteristics of the demand served. Network planning can be divided into two distinct phases:

- design (analyzing what markets should be served, and what business implications will be reflected in the airline's operations and profitability);
- scheduling (outlining how many flights should be scheduled for a determined market and at what time, and what business implications will be reflected in the airline's operations and profitability).

According to Doganis (2019), network planning is one of the decision areas dependent on an analysis of demand for the transport of passengers and/or freight. It is vital for airlines to have a full understanding of the demand they want to satisfy, in order to maintain a balance between unit costs, unit revenues and load factor.

3.2 Network structures

Based on the airline's combination and match of the O&D (Origin and Destination) markets served, airlines create networks of routes, which present functional structures. The two most common network structures are **Hub-and-spoke** and **Point-to-point**.

To define a network structure, Brueckner (2004) uses the following A-H-B model.

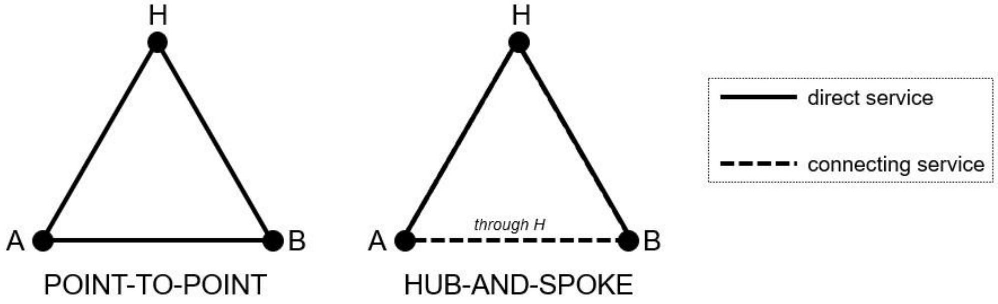

Figure 1. Network structure model (Brueckner 2004).

Three cities (A, B, and H) are served; demand for travel is present among the cities, with three O&D markets (A-H, B-H, A-B).

A hub-and-spoke structure directly serves the markets AH and BH, while the AB market is served only through a stop in H. A combination of local traffic (AH and BH) and connecting traffic (AB) is carried on the routes.

A point-to-point structure offers a direct service to all the three O&D, virtually eliminating the connecting traffic, therefore focusing only on local traffic for all the three city pairs.

3.2.1 Hub-and-spoke

In a Hub-and-spoke model, the airline channels its traffic from a major airport (the “hub”) to several regional, international and intercontinental destinations (the “spokes”) and vice versa, creating a large combination of one-stop connections. Larger airlines also rely on the operation of more than one hub.

From a commercial perspective, a hub is the combination of three factors (Holloway 2008a):

- A well-established physical infrastructure in a major airport (enabling smoother opportunities of connection for passengers and/or freight);
- The airline’s operational capability in a large scale (meaning the ability to connect and channel traffic flows);
- Additionally, a solid set of airline partnerships (to further enhance connectivity and strengthen its dominance).

A hub-and-spoke model builds up connectivity among all the “spokes” of the network. In a single-hub network, the one-stop city pairs possible are $\frac{n(n-1)}{2}$ (where n = number of cities served to and from the hub). For example, a hub serving 100 destinations would consist of 4950 city pairs, offering therefore a considerable number of combinations and opportunities of connectivity for any of the “spokes”. Hubs are organized in time banks, which are the combination of a set of arrivals followed by a set of departures. Despite the benefit of connectivity, when a hub-and-spoke network is designed with condensed banks, meaning that many flights arrive and depart in a same span of time, it can result in high airport congestion: for this reason, On-Time Performance (OTP) is a crucial indicator to measure the operational effectiveness of a hub (Abdelghany & Abdelghany 2010)

3.2.2 Point-to-point and minor structures

A **Point-to-point** structure, on the contrary, directly serves an O&D market bypassing a major hub and therefore focusing on the direct demand between two cities. Airlines adopting a point-to-point strategy usually have one or multiple bases, stimulating the demand on markets with the benefit of a direct connection. In this network structure, bases do not operate as hubs, commercially not offering any one-stop connection opportunities.

Other minor network structures exist; however, their natures are very similar to either a point-to-point or a hub-and-spoke model, with their characteristics mostly leaning towards one or the other. Among these minor structures, the **linear network** is worth a mention: it connects the points of origin and destination indirectly, making one or more stops on the way, collecting and disembarking passengers at each stop, similarly to how a commuting bus or train trunk route would act. The benefit of a linear network is that several routes with lower yields can be incorporated into a single one, combining different traffic flows: for example, on a route from a point A to a point B continuing to a point C, the combination of A-B, A-C and B-C can be more commercially viable compared to three distinct services. In such network, usually the origin and/or the final destination point act as hub or operating base (Holloway 2008a).

Airlines do not strictly rely to a single network type, but they very often combine different characteristics of network structures. For example, an airline focusing on point-to-point traffic could commercially offer connections from one of its focus cities, simulating a hub; also the reverse might apply, where an airline relying on a hub-and-spoke model could have part of its offer virtually untied to the connections, or it could have additional secondary bases focusing on point-to-point traffic.

3.3 Relationship between network structures and business models

As mentioned in Chapter 3.1, a network of routes is the result of an airline’s business strategy. Based on this, according to the canonical theories of airline management, two business models exist: Full-Service Network Carriers (FSNCs, also called Legacy Carriers) and Low-Cost Carriers (LCCs).

Osterwalder (2004) defines an airline business model as “a description of the value a company offers to one or several segments of customers and the architecture of the firm and its network of partners for creating, marketing, and delivering this value”. Holloway (2008b) states that any airline business model has two main elements: revenue (how revenues are made) and cost (the financial consequences of the revenue). According to this differentiation, the FSNC and LCC models are characterized as follows:

	FSNC	LCC
Revenue	Full-Service	No-frills, use of ancillary revenue
Cost	Outdated, not financially competitive	Lean with a cost-cutting strategy

Table 1. Basic characteristics of business models (Holloway 2008).

Full-Service Network Carriers, historically developed from the former state-owned flag carriers, offer a wide network of short-, medium- and long-haul, covering as many as possible O&D pairs, with a diversified fleet. They usually belong to a global alliance, and they engage in several commercial agreements with other airlines. The product offered to the customers is diverse, with several levels of fare classes, but usually offering a range of services inflight and at the airport. FSNCs tend to operate hub-and-spoke networks.

Low-Cost Carriers, developed first in the United States of America around the 1970s, rely usually on short-/medium-haul, point-to-point services on intra-continental markets. They have a single-type fleet, allowing a higher standardization and lower maintenance costs, with a high level of aircraft utilization. Based on a no-frills revenue strategy, every differentiation element (ancillary products) can be purchased separately.
In most cases, LCCs operate point-to-point networks.

Fu et al. (2019), analyzing the case of the American Low-Cost Carrier Southwest Airlines, state that airline’s success relies on its point-to-point network: while in a hub-and-spoke network the airline’s airport presence is strengthened by connections, Southwest has done the same by combining the connecting and the direct demand into non-stop, direct services to and from focus cities, without the costs of operating a hub. Also, by serving substitute airports/markets out of the same airports, the airline managed to reinforce its presence in several O&D markets with a differentiated model. The model adopted by Southwest has been then adopted and replicated all over the rest of the world with successful results.

Exactly as for network structures, business models are not firmly and strictly followed, making such categorization more complex: Magdalina & Bouzaima (2021) state that, at least in Europe, most of the airlines are stepping away from the LCC/FSNC categorization, placing themselves in a hybrid spectrum which, case by case, combines selected features of both “canonical” models; also, they affirm that LCCs are less keen on moving towards hybrid, while they rather hold to their “original” business model. According to their study, however, network structure is a fixed characteristic from where carriers, in most situations, does not transition to a different model: it is quite hard to find in history an airline completely transitioning from point-to-point to hub-and-spoke and vice versa.

3.4 Regional aviation, regional feeds and their role in a hub-and-spoke model

Usually incorporated into a wider system of routes, a regional network includes short-haul routes, both domestic and international. Due to the lack of a uniform definition of a regional route, Black (2022) argues that a regional flight can be defined as such based on which aircraft type is used to operate it, usually a smaller jet (e.g. Embraer 170/190) or a propeller (e.g. ATR 42/72), Although this definition is not fully accurate, since a regional route can be flown by larger aircraft if sufficient demand is present, this statement is true in most of the cases.

According to Holloway (2008a), a regional network within a carrier is “an archetypal example of traffic feed”, providing strategic value for different reasons:

- it serves secondary/tertiary markets, which, in some cases, would be otherwise unserved;
- it is able to generate more demand towards the other “spokes” of the network, creating seamless opportunities of connection;
- If solidly built, it can guarantee market control over some regions, strengthening a carrier’s hub dominance.

However, the combination of higher frequency and the use of smaller capacity on regional routes results in a financially unstable market, more expensive to operate in terms of CASK (Cost of Available Seat Kilometers). For this reason, major FSNCs throughout the years have tried to solve this financial issue by either assigning such services to smaller airlines, or opening own subsidiaries (which is the case in most of the major European FSNCs). Thus, when the population in a catchment area is not large enough to sustain service from even the smallest airplanes in FSNCs’ mainline fleets, but it can work with smaller regional jets, subcontracting such routes to a regional branch is the most cost-effective option for a carrier. This practice is common among larger airlines in the USA, where many regional airlines do not carry their own operations but they rely exclusively on subcontracts and partnerships with major FSNCs. The table below shows the partnerships between regional and some mainline carriers in the USA (Aeroguard 2021).

		Mainline US carriers			
		United (UA)	Delta (DL)	American (AA)	Alaska (AS)
Regional airlines subcontracting	SkyWest Airlines	●	●	●	●
	Republic Airways	●	●	●	
	Envoy Air			●	
	Mesa Airlines	●		●	
	Horizon Air				●
	PSA			●	
	Endeavor Air		●		
	GoJet	●			
	CommutAir	●			
	Piedmont Airlines			●	
	Air Wisconsin	●			

Table 2. Main American regional airlines and their partnerships with mainline carriers.

In the case of Europe, Redondi et al. (2013) affirm that airports handling less than 2 million passengers per year (hereby referred as “small airports”) play a vital role in regional connectivity, especially in countries where remote and peripheral regions are less accessible with different means of transport. In some cases, without the presence of such small airports, there would be a 60% loss of connectivity, with peaks of a 40% increase in average travel time for areas. The most affected countries in the continent, according to the study, would be the Nordic countries (Norway, Denmark, Sweden, Finland), Spain, Italy and some parts of France.

Bråthen & Eriksen (2018) investigate further the matter of regional aviation in Europe from the perspective of Public Service Obligation (PSO), a system instituted by the European Commission granting financial support to airlines serving regional secondary routes (very often in geographically remote areas). PSO routes, despite being in most cases financially unviable for airlines, are usually vital for the economic and social development of some regions, which is why regional and/or national authorities grant aids to serve such routes.

The PSO services are designed by the tendering authorities (country or regional governments) and they need to meet certain criteria, usually including at least the following:

- Provide accessibility to a capital city, an important economical center of the country or an airport with international services;

- Set an adequate number of round trips with capacity adjusted to the demand;
- Set an appropriate scheduling system meeting the needs of the demand (usually guaranteeing connections to a larger hub).

A similar system is used in the USA, under the name of Essential Air Service (EAS).

3.5 Elements of scheduling

Holloway (2008c) describes scheduling as the response and the impact on an airline's demand Four factors need to be taken into consideration if effective scheduling wants to match the demand:

- Frequency (how many times a day, a week, a month a route operates)
- Timing (at what time of the day the flight leaves)
- Reliability (the schedule's adherence to slot restrictions and on-time performances)
- Turnaround times (the time spent on the ground by aircraft between two flights)

In the case of a hub-and-spoke model, the flights to and from a hub must be organized in order to guarantee smooth connectivity opportunities. As an example, two points A and C could be virtually connected through a point B (the hub); however, with the schedules of flights A-B and B-C not coinciding, an unfavorable offer to the customer is given in terms of travel time. If there is a strong demand between the points A and B, the airline might consider optimizing its scheduling options in order to guarantee a more competitive one-stop offering.

A practical example of this scheduling matter can be found in Finnair's Summer 2022 (S22) and Winter 2022-2023 (W23) schedule; via its Helsinki Airport (HEL) hub, the airline offers connections from the United States to India and vice versa. The following example shows how a schedule can be optimized, offering a smoother connection, based on the transit times between New York J.F. Kennedy Airport (JFK) and Delhi Indira Gandhi Airport (DEL) – both destinations are served on a daily basis:

		Arrives in HEL	Departs from HEL	Transit time	W23 vs. S22
JFK to DEL	S22	10:10	18:15	08h05	-05h35 travel time reduction
	W23	14:55	18:35	03h40	
DEL to JFK	S22	14:35	13:00 (next day)	22h25	-19h05 travel time reduction
	W23	13:45	17:00	3h15	

Table 3. Example of schedule optimization; case Finnair JFK-HEL-DEL & vv.

As shown in the table, presumably because of an increase in demand on the city pair, the airline has adjusted appropriately the schedule for both destinations, making the connection more appealing in terms of travel time (especially on the DEL to JFK direction).

3.6 Network planning and scheduling process

Holloway (2008c) summarizes the full process of network planning and scheduling in the following steps:

1	Decide which markets will be served according to the demand forecasts (with the help of marketing and network design)
2	Assume a market share based on the forecasts
3	Draft the frequencies of the service, according to the possible pricings and load factors, in order to maximize revenue
4	Adjust the frequencies (3) according to potential market preferences, possible connectivity opportunities, and availability of airport slots
5	Assume and establish block times for each flight
6	Establish turnaround times
7	Assign an aircraft type to every flight (taking into account aircraft flying hours, cycles and maintenance requirements)
8	Assign a specific airplane (tail number) to a specific flight
9	Assign human resources (rostering crews)
10	Predict competitors’ strategies and market reactions

Table 4. Scheduling process (Holloway 2008c).

4 Methodology

This chapter discusses the usage of an appropriate research method, and it presents the processes and the tools used to collect data and insights, evaluating their reliability and their meaning for this research.

4.1 Research questions

The research question of this study is the following:

Can a possible network of electric aircraft suit in an airline's business model?

With the sub-question being:

What potential markets can implement such innovation and how?

4.2 Research objective and purpose

The final objective of this research is to identify under what premises a route network for electric aircraft can be conceived and in what ways it can suit into an airline's business model, and, based on such premises, what could be some of the potential markets ready to implement an electric network.

The drive towards electric aviation is a growing and evolving trend within the industry. For this reason, this study wants to raise even more the awareness and the already existing interest into the topic, but shifting it from a purely technical matter to a business case with a commercial perspective.

4.3 Research method

While it can be argued that this study utilizes a mixed methodology, therefore with the use of both research methods, this study leans mostly towards a quantitative methodology approach.

McKim (2017) states that the use of a mixed approach in research "combines the strengths of each methodology and minimizes the weaknesses", offering different points of view. With a very diverse set of data, combining, among others, numerical figures, facts, and theoretical concepts, a study can tap into the characteristics of both qualitative and quantitative methods, with a major tension towards either one or the other. Also, during the course of the research, one method may lead to the discovery of new insights which inform and are followed up through the use of the other method.

According to the theory of business research provided by Bryman and Bell (2011), qualitative research uses an interpretivist way of research, while quantitative research relies on a purely scientific, experimental method. Since this research follows a rather pivotal scientific method, based on hypotheses and assumptions generating results, under this interpretation it can be affirmed that this research takes a quantitative approach.

Moreover, according to the same authors, another substantial difference between qualitative and quantitative research is that the former has a focus on behavior, and the latter on meaning. Strictly on this sense, it is possible to say that this study leans completely on a quantitative methodology: indeed, no subjective and personal opinions are contemplated in this study.

This study takes an exploratory approach of the matter, meaning that the study explores research questions that have not previously been studied in depth; the reasoning behind this research is inductive, meaning that the known premises are gathered and then used and practically applied to generate conclusions (Saunders et al. 2012).

4.4 Research materials and tools

The data gathered for this study consist majorly of secondary data, whose sources are discussed below. Data have been collected through the sources available to a bachelor-level student, therefore without access to official data, for example, from airlines or airports. Different airlines have been contacted in order to provide extra insights and inputs in this research; however, no answer has been given to the author, leaving the data collection to be based mostly on academic research, books, specialized websites, social media (which have proven to be an important source, especially LinkedIn) and own observation of the airport environment.

A large portfolio of academic articles has been used for this study, with one of the main sources being the Journal of Air Transport Management. Many data have been gathered also from peer-reviewed articles coming from different fields of expertise, such as engineering, renewable energies, and new technologies . The partial use of such diverse articles gives a solid support for a more complete overview of the world of electric aviation, also exploring insights external to the commercial sector.

A consistent portion of the insights gathered for this study comes from the main manufacturers' official websites: their webpages are extremely detailed and explain thoroughly the processes, the developments and the future plans of the aircraft and the companies. Also, articles and press releases directly issued from airlines, manufacturers and various stakeholders involved provide official and accurate information useful for the research.

The combination of existing research literature and official websites is able to provide a complete overview of the main topic of study, of which Chapter 2 is the result.

The review of existing literature has been completed by a theoretical review of the basic concepts and theories of airline network management (Chapter 3); for this, two Aviation Management theory books have been used: *Straight and Level* by S. Holloway (2008) and *Flying Off Course* by R. Doganis (2019).

The data about current schedules, equipment and seats are retrieved from flightconnections.com and the airlines' official websites and booking tools (including among others Finnair, SAS, Nyx Air). Despite not being canonic sources for a thesis, the study of a brand new field of research requires additional non-academic inputs. The data about distances and the maps in Chapter 6 have been generated through the online tools Great Circle Mapper (http://www.gcmap.com/) and Great Circle Map (https://www.greatcirclemap.com/).

4.5 Use of academic research in a new field of study and its limitations

Conducting research in a brand-new field of the industry implies that most of the sources are not academic papers: while a wide range of peer-reviewed has been used on this study, the majority of the information about electric aircraft comes from the manufacturers' official websites and press releases.

The current academic research about electric aviation is limited to matters related mainly to engineering, airworthiness and electrical systems; the commercial side has been touched only in a limited number of papers in a marginal way.

Also, despite the current forecasts state that aircraft will enter service later in 2026 (in the case of Heart Aerospace), internal problems (as an example, operational issues during the test flights) might occur, pushing forward this planned date. This is an existing issue when investing time and research into a completely new technology, starting from scratch, which might disrupt the market. It must be recognized, however, that the effort put by the aviation stakeholders towards a greener industry are promising for a rigorous timeline. Additionally, the always changing social and geopolitical environment might as well have an impact on the current projects and research.

4.6 Flow of information

Since, as of August 2022, all the current manufacturers of electric aircraft are undergoing testing and prototyping phases, news are published almost on a daily basis, bringing a large amount of information in a very fast-paced way. The researcher’s continuous attention and constant monitoring are required to keep track of any updates. The main channel to keep up with the continuous flow of updates has been LinkedIn, where companies have been mostly posting their most recent milestones.

During the final stages of the study, on 15th September 2022, Heart Aerospace announced the abandonment of the ES-19 to follow up on the upgraded ES-30 prototype, along with several major announcements regarding, among others, new customers and Letters of Intent (LOIs). This has led to some major changes, especially within the results of the study.

The same continuous flow of information applied to the case of PSO services in Finland, analyzed in Chapter 6.4. Since the previous PSO tender finished in August 2022, and the next tender will start at the end of October 2022, the study has been conducted in the period of transition between the two: while this has brought many additional insights into the research, several particulars of the study had to be adjusted or completely changed.

5 Framework for electric aircraft network planning

This chapter examines whether a network operated by electric aircraft can be planned, and in what ways it can be structured, including the characteristics of the markets, the routes and the airlines that might adopt, based on the information acquired so far; it will be investigated what network structures and what airline business models could suit best such routes, and it will be reviewed whether the current potential customers' business models are suitable for implementing electric aircraft.

It is important to note that, hereafter in this study, it will be assumed that the infrastructure is already existing.

5.1 Characteristics of ES-30 and Alice and comparison with existing jets

The table below presents some technical specifications about the two aircraft prototypes, along with the main differences between Heart's first and second project. It has been decided to provide a comparison between the two electric jets and two of the smallest commercial regional jets in the market: the Saab S340 and the ATR 42-300. All the data retrieved come from the manufacturers' official websites.

	ES-19 Heart Aerospace (Sweden)	ES-30 Heart Aerospace (Sweden)	Alice (Commuter) Eviation (Israel – USA)	*S340 Saab (Sweden)*	*ATR42-300 ATR*
Expected entry into service	*2026*	2028	2024	-	-
Seats	*19*	30	9	*34*	*48*
Seats configuration	*1-1*	1-2	1-1	*1-2*	*2-2*
Take-off distance	*2460 ft 750 m*	3610 ft 1100m	2040 ft 620 m	*4220 ft 1285 m*	*3576 ft 1090 m*
Maximum cruise speed	*N/A**	N/A*	250 kts 463 km/h	*271 kts 502 km/h*	*266 kts 493 km/h*

Range	*400 km* *250 mi* *216 nmi*	200km (fully electric) 400km (50% electric, 50% fuel)	815 km 506 mi 440 nmi	*870 km* *540 mi* *470 nmi*	*815 km* *506 mi* *440 nmi*

**For the sake of this research, it will be assumed that the maximum cruise speed will be the same for both models.*

Table 5. Features of ES-30 and Alice and comparison with two regional jets.

As shown from Table 1, there are some substantial differences: the two electric planes will be able to access smaller airports, thanks to their short take-off distance, around half compared to the current regional jets, thus opening new market opportunities. However, the most solid difference is on the number of seats: *ES-30* and *Alice* can accommodate a significantly lower number of passengers compared to what the current aircraft market offers.

Cruise speed, at least in the case of *Alice*, is similar to Saab 340 and ATR42; therefore, for this research it will be assumed thereafter that flight times would be approximately the same as the ones of current regional jets.

5.2 Generalities of potential markets

Based on the two manufacturers' missions and the current data of the two aircraft prototypes, it is easy to affirm that the main target for electric aircraft will be, at least on a first stage, on regional networks of short-haul routes. In the case of *Alice*, the range of such routes would be proportionate to the one of current regional aircraft (around 800 km); for *ES-30*, that would be the half (400 km), therefore on extremely short routes.

Due to the low number of seats, three kinds of routes can be a potential target:

- Routes to, from or between secondary and tertiary regions, with very low demand, or combinations of routes with low demand;
- Domestic PSO/EAS routes;
- Routes with medium to high demand and high daily frequencies (trunk routes).

Also, always thanks to the low number of seats, airlines would be able to open markets which were commercially unviable before. The demand of a remote region, for example, would support and stimulate the offer of 19 seats a day, but not enough to fill a plane of 48 seats.

Because of their STOL capabilities, both planes would be able to reach smaller airports which, nowadays, cannot be served by larger jets due to their short runways.

5.3 Suitable network structures and business models

With a focus on short-haul routes, *ES-30* and *Alice* could easily and efficiently fit in a Hub-and-spoke model. Thanks to their suitability for regional networks, the two aircraft could become an airline's backbone for serving the "spokes" located closer to a hub (*figure 2a*). With their use, a carrier with a hub-and-spoke model could explore more regional opportunities, benefitting not only the airline with more additions to its network, but also the newly served areas, with a direct link to a hub, and, consequently, with more one-stop connection opportunities.

For these reasons, Full-Service Network Carriers would be an optimal clientele for *ES-30* and *Alice*. Also, FSNCs' regional branches and subcontractors (mentioned in Chapter 3.4) would as well represent good target customers, as their focus is, indeed, in short-haul feeder routes.

When it comes to a point-to-point structure, the use of regional, electric aircraft would not completely fulfill the needs of the markets, due to their limited capacity and short range: as a matter of fact, it is unlikely that a carrier adopting a point-to-point strategy (namely an LCC) would invest in direct, regional service with low demand. Moreover, based on the cost structure of LCCs, adding a new aircraft type to a standardized fleet would result in higher maintenance and labor costs, contrasting LCCs' business philosophy.

Moreover, the use of a linear network could be a good fit for the two new aircraft, especially in the case of *ES-30*: its short range would be an asset when designing journeys in a *trunk-route* model. For instance, a small linear network of regional destinations inscribed into a larger hub-and-spoke system could boost the carrier's regional connectivity, with a good impact on the newly connected areas, too (*figure 2b*).

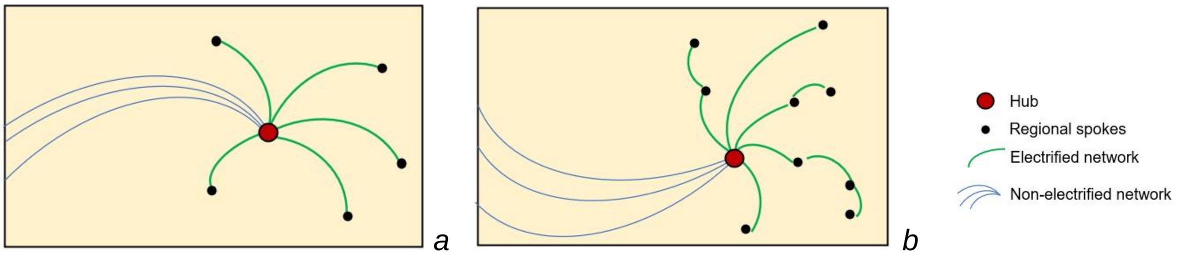

Figure 2. Direct feeder into a hub-and-spoke network (a); direct and linear feeder combination into a hub and spoke network (b).

5.4 Assessment of some current potential customers

As mentioned in Chapter 2.4, as of 2022 some airlines have expressed interest in including electric aircraft in their fleets. By analyzing their business models and network structures, it is already possible to assess whether these airlines would make of electric planes a good fit in their company.

Finnair is a Finnish network carrier, specialized in connecting Europe, North America and Asia via its hub in Helsinki, Finland. With a diversified network of around 100 destinations, the airline also serves domestic and regional destinations (through its subsidiary Norra) with a mix of ATR72 and Embraer 190. Among its current shortest routes, there is Helsinki-Tallinn (101 km), Helsinki-Tampere (143 km) and Helsinki-Turku (150 km).
Finnair makes a good potential candidate for using electric aircraft, thanks to the presence of a strong and diversified regional network of short-haul routes (especially the above-mentioned routes); also, adding electric aircraft to its fleet would be a natural step for the airline, which has a strong focus on sustainability.

Wideroe (Norway) is the largest regional airline in Scandinavia, connecting around 40 destinations, both domestic and international. With a mixed fleet of Bombardier Dash-8 100/200/300 and Embraer E190-E2, Wideroe has the plan to replace its fleet of fossil fuel-powered aircraft on the domestic short runway network by 2030.
Because of Norway’s complex morphology, Wideroe’s air network represents in several cases a vital connection for some remote areas, connecting them to the closest centers and hubs around the country; a substantial portion of the airline’s network is made up of PSO routes (*see Appendix 1*), making Wideroe another good candidate for implementing electric aircraft.

Scandinavian Airlines (SAS) is the flag carrier of Denmark, Sweden and Norway. The airline offers a network of some 125 destinations, with a strong focus on regional routes in its home countries. In September 2022, the airline announced its interest in the ES-30 project. Just like for Wideroe, Scandinavian routes represent an excellent target for Heart’s aircraft, including, for example, Aalborg to Copenhagen (239 km) or Stockholm-Arlanda to Visby (223 km). The figure below shows a possible electrified network in an earlier stage:

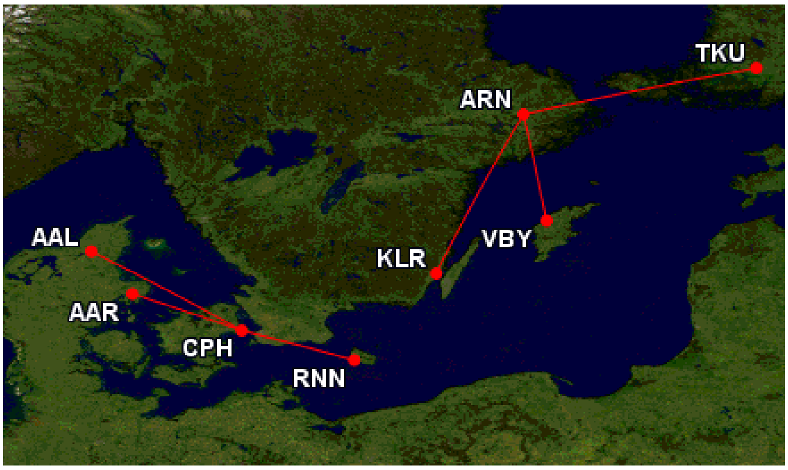

Figure 3. Possible initial implementation of electric aircraft in SAS' network.

Mesa Airlines is an American regional carrier founded in 1982. Not operating services on its own, the airline operates subcontracted regional services on behalf of United Airlines (UA) and American Airlines (AA), meaning that the flights are sold and marketed by UA and AA but operated by Mesa. Thanks to a strong partnership with UA, Mesa Airlines is planning to add up to 100 ES-19 (later converted into ES-30) aircraft into its fleet. According to some preliminary studies conducted by United, the ES-30 could operate on more than 100 of its current regional routes and opening new short-haul opportunities currently unviable, for example, San Francisco International Airport (SFO) to Modesto City County Airport (MOD), covering a distance of 125 km.
Being a regional airline focusing mostly on feeder operations for mainline carriers, also Mesa Airlines has suitable model, network and strategy for putting this innovation into effect.

Sevenair is a Portuguese regional company operating a single route hopping between secondary cities in Portugal; it ordered 6 ES-30 to replace its current fleet. Currently, on the route Sevenair deploys a mix of Dornier 228 and BAe Jetstream 32 aircraft, both able to carry up to 19 passengers. All the segments on the route are under 255 km long, with a total distance of 612 km. At full capacity,

Figure 4. Sevenair's routing in Portugal.

5.5 Suitable networks and markets: a summary

The following table sums up all the specifications discussed above, showing that in the near future a network of electric aircraft is possible to be implemented. regarding what should be considered to plan the service of electric aircraft, including the characteristics of routes, markets, airlines and networks.

In the next chapter, these generalities will be applied in some practical examples designed by the author.

GENERAL FRAMEWORK: NETWORK PLANNING FOR ELECTRIC AIRCRAFT	
Range	• Short haul • 200-400 km (*ES-30*) – 800 km (*Alice*)
Routes	• Regional routes, domestic services • PSO/EAS routes • Short routes needing high frequency
Markets	• Remote areas • Secondary/tertiary markets • Generally, markets supporting low demand • Small aerodromes with short runways (STOL)
Network structures	• Regional/domestic feeders for hub-and-spoke

	• Linear networks, triangular routes, trunk routes, also in combination
Business models	• Network carriers • Regional airlines, regional branches of mainline carriers • Subcontracting airlines
Opportunities	• Serve markets with low demand in a cost-effective way • Serve airports which now cannot accommodate larger jets • Generate vital connectivity for peripherical, remote areas

Current potential customers	• Finnair (network carrier, regional feed) • Wideroe (regional carrier, PSO, remote areas) • Mesa Airlines/United (regional carrier, subcontractor, EAS) • SAS (network carrier, regional feed) • Sevenair (small airline, short domestic network)

Table 6. Generalities of Network Planning for electric aircraft.

6 Practical cases

This chapter discusses several practical examples of how networks of electric aircraft could look like. The first case will be a critical comment of an existing conceptual network which has been revealed to a Finnish newspaper in February 2022, while the remaining cases are created by the author; the scenarios are all based on the framework discussed in Chapter 5, along with more opening for further research.

6.1 Initial assumptions

In order to standardize the cases of this study, some assumptions will be applied:

- As mentioned in Chapter 5, it is assumed the infrastructure needed is existent and functioning;
- The technical data from Table 5 are valid for the cases;
- Heart Aerospace hypothesizes the charging time of the airplane's battery as maximum 40 minutes per average mission, so turnarounds will be standardized to 45 minutes each, and in the case of one-stop flights and linear networks, the stops in between are standardized to 25 minutes;
- The flight times used in these cases will be the ones of existing regional planes in existing routes + 5 minutes (e.g. 01h15 + 00h05 = 01h20);
- When referring to current weekly schedules, the samples are taken from the week 38 of 2022 (Monday 19.09 to Sunday 25.09), unless stated otherwise;
- The data about mileage and Great Circle Distance (GCD) are retrieved from gcmap.com.

6.2 Case 1: assessment of an existing potential network: Enontekiö (Finland)

In February 2022, Marko Halla, CEO of Enontekiö Airport (ENF) in Lapland, outlined in an interview to the Finnish newspaper Yle that he plans to turn his airport into a small hub connecting

Enontekiö Airport wants to position itself as a small regional hub linking the small communities of Finnish Lapland and the neighboring municipalities of Sweden and Norway. Due to the long driving times, it is currently quite difficult to move around the Arctic regions of the three countries. For example, driving between RVN and TOS takes around eight hours; with an air connection, the travel time would drop to around one hour. The demand, despite not being extremely high, is existent:

along with the touristic flows, many Finns live and work in Northern Norway, and several universities of the area cooperate with each other, guaranteeing a flow of potential passengers.

In the article, Halla explains that at first the experiment of a hub will be tried over the next years, first with a turboprop plane, and then transition to a hub for electric aircraft. (Tanskanen 2022)

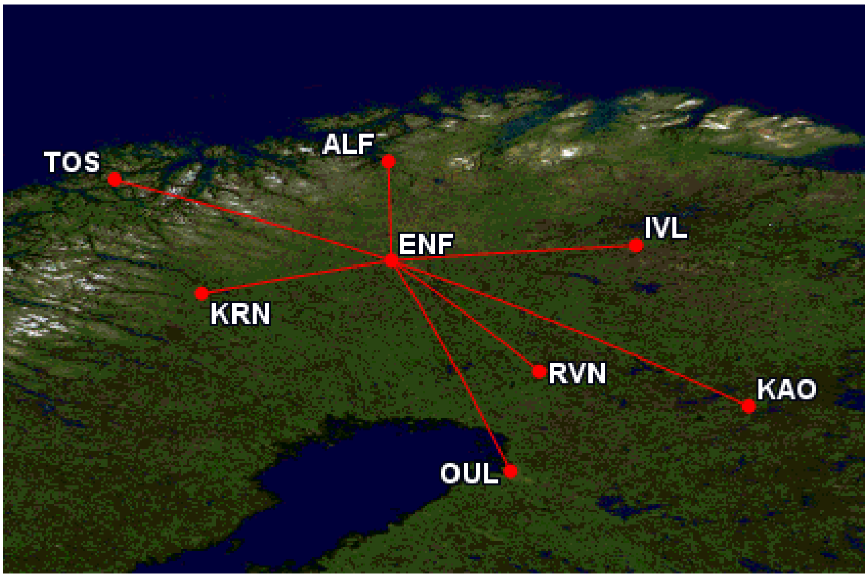

Figure 5. Electric network planned for ENF Airport. Source: Yle.

Connecting these smaller cities in the remote North can be a beneficial way to support and link such isolated areas within each other through Enontekiö Airport, which would act as the central base. Indeed, as shown in the map above, Enontekiö has a central position in the region, making it geographically well located to act as a small hub: for example, according to the Great Circle Map server, a routing TOS-RVN through ENF would be just 7 km longer than a direct route. This way, frequent commuters would have an easier and quicker way to move between the cities through ENF, avoiding half a day on the road.

More considerations on the demand can be made for this case:

- First, both ES-30 and Alice would be suitable for this project, as all the routes fall within their maximum range and their low capacity would match the low demand.
- Since Lapland is a destination focusing mostly on Winter tourism, the demand would be highly dependent on seasonality: during winter season, ENF could channel passenger flows between the destinations. For example, travelers might want to visit more destinations during their holidays, or tourists in Finnish Lapland might enjoy a day trip in Tromso.
- If one of the goals is to guarantee connections between remote communities, the schedules must be designed so that it is possible to commute within the day, for example with frequencies in the morning and in the evening,

The creation of an Arctic hub in ENF is a valuable example of how a possible route network for electric aircraft could look like. The network structure, the routes and the demand are all suitable for the aircraft taken into consideration. Additionally, opening these routes would largely benefit the local economies, making them more accessible and giving them easier connections. An excellent way to promote the ENF hub would be a tight collaboration among the local communities of the three countries, offering such flights, for instance, in combination with tour packages in Lapland, benefiting simultaneously tourism, local workforce and a new aviation market in the area.

6.3 Case 2: implementation into Finnair’s network

It has been discussed in Chapters 2.4 and 5.4 that the Finnish network carrier Finnair could be a potential user of electric aircraft thanks to its suitable business model and network strategy, and it has expressed interest in Heart Aerospace’s *ES-30*. It will be analyzed now how this aircraft could fit in the airline’s network.

The following map shows what current routes within the airline’s network can be reached within the range of *ES-30*.

- Tampere, Finland (TMP) – 143 km
- Turku, Finland (TKU) – 150 km
- Vaasa, Finland (VAA) – 348 km
- Mariehamn, Finland (MHQ) – 282 km
- Kuopio, Finland (KUO) – 335 km
- Tallinn, Estonia (TLL) – 101 km
- Tartu, Estonia (TAY) – 245 km
- Riga, Latvia (RIX) – 382 km

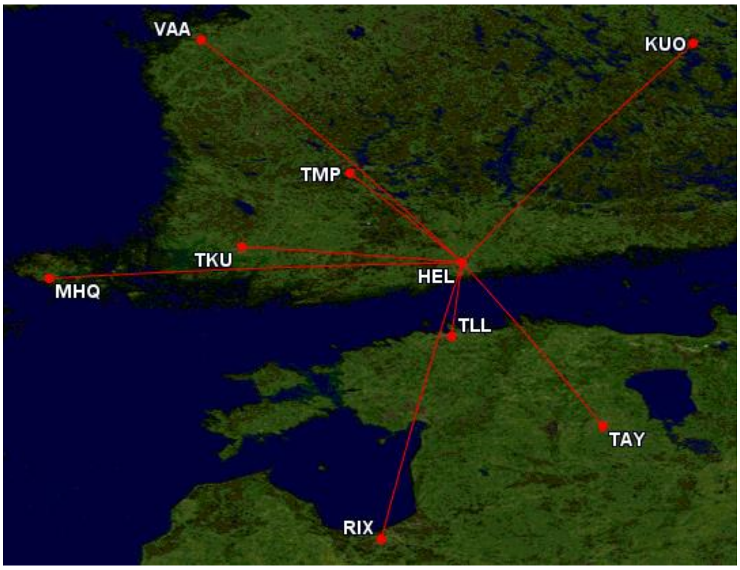

Figure 6. Potentially electrifiable network within Finnair’s regional routes.

KUO, VAA and RIX represent borderline cases: due to length being very close to the maximum range of the airplane, operating these routes would not allow to have some spare range in case of emergency.

However, the remaining routes would suit appropriately ES-30's operations. While TLL is a key feeder route for Finnair's network (its situation is discussed later), TKU, TMP, MHQ and TAY represent low-demand, low-frequency services, all operated by ATR72-500. TKU and TMP are currently served 6 times a week, with the outbound sector leaving around 00:00 and returning to HEL before 07:00, offering a total of 408 seats a week (one-way). Additionally, during the day some bus services to replace possible extra air services, in an effort to cut emissions. MHQ and TAY are served respectively 4 and 5 times a week, with a weekly offering of 272 and 340 seats a week; TAY has been suspended at the end of October 2022.

In order to accommodate an aircraft with less capacity, yet matching the existing demand, frequencies need to be added. The table below examines how the seat offering changes in different scenarios.

	Same frequencies	% of existing demand	Doubling frequencies	% of existing demand	Tripling frequencies	% of existing demand
TKU/TMP	6 flights/week 180 seats/week	44%	12 flights/week 360 seats/week	88%	18 flights/week 540 seats/week	132%
MHQ	4 flights/week 120 seats/week		8 flights/week 240 seats/week		12 flights/week 360 seats/week	
TAY	5 flights/week 150 seats/week		10 flights/week 300 flights/week		15 flights/week 450 seats/week	

Table 7. Frequency and capacity match on selected regional routes operable by ES-30.

If the current frequencies are kept, the operation of ES-30 on these routes would cover around half of the existing seat offering; if the frequencies are doubled, the seat offering would almost match the existing offer of frequencies would result in additional spilled capacity. For example, if the HEL-TAY route registers on average a load factor of 50%, there would be no need to add frequencies.

The Helsinki-Tallinn route will be now taken into examination. Between 6 and 9 flights are offered every day in the city pair, with a mix of ATR72-500 (68 seats) and Embraer E190 (100 seats), as per the table below.

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
ATR flights	7	7	8	8	7	5	4
E190 flights	2	2	1	1	2	2	2
Daily seats offer	676	676	644	644	676	540	472

Table 8. Current seats offer on the HEL-TLL route (one-way).

With a 30-seater plane, reaching the same number of seats offered at the moment obviously requires a higher number of rotations: to meet the current demand of Mondays, for example, the ES-30 fleet would need to fly 23 times a day. This might cause additional congestion, especially in slot-restricted airports; however, a high number of frequencies would benefit TLL with more time-efficient connections through HEL, as well as a wide range of choice for the direct demand.

A tentative schedule can be found in the *Appendix 2*: four planes could operate altogether 30 rotations a day (between 05:00 and 00:00); on average, there would be around one flight every 30 minutes, with an overall offer of 900 seats a day at the maximum. The case considers a full aircraft utilization; ideally, one or two extra aircraft could be allocated to the city pair to complete the offering, for eventual additional demand or as spare equipment.
Some additional observations can be made on this model:

- Two aircraft would stay overnight in TLL, offering two early-morning departures.
- A high number of departures spread during the day offers connections opportunities on all of Finnair’s departures banks (07:00-08:00 and 16:00-17:00 for European flights, 12:00-14:00 and 16:00-18:00 for intercontinental flights).
- The benefit for the time-sensitive direct demand on the segment is the wide choice of flight options, offering a service similar to a commuter bus or train.

6.4 Case 3: PSO services in Finland

As introduced in Chapter 3.4, the operation of some domestic regional routes in Europe is subsidized by the local governments under PSO (Public Service Obligation). In Finland, the routes between Helsinki and seven regional airports are under PSO: Pori (POR), Jyväskylä (JYV), Kajaani

(KAJ), Joensuu (JOE), Savonlinna (SVL), Kemi (KEM) and Kokkola (KOK), with the latter two connected as a triangle route to the capital.

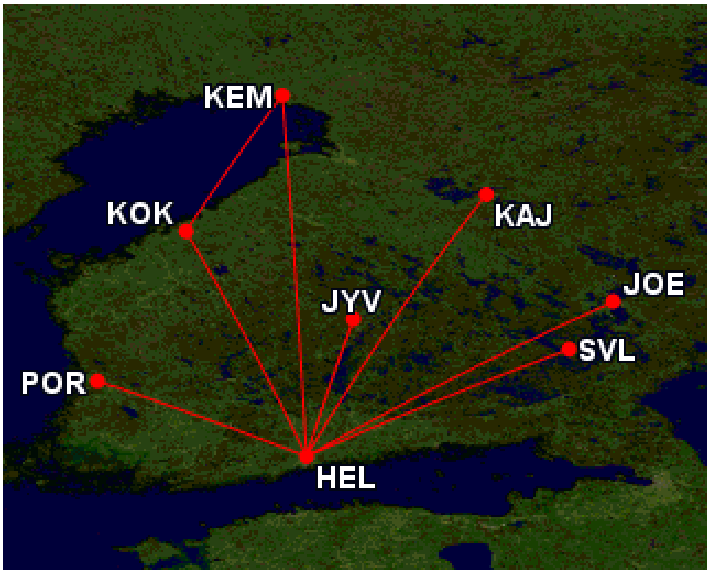

Figure 7. PSO network in Finland.

The operation of these routes is organized in three different tenders. The one for the route to POR is organized by the city of Pori, and the operator is the Hungarian carrier BASe Airlines, operating the route three times daily on weekdays. Another tender is one for the HEL-SVL route, where the Lithuanian carrier Transaviabaltika has been granted to operate the route until 2024.

The situation is different for the remaining five cities, whose tender is organized by the Finnish Transport and Communications Agency (Traficom). The latest tender has been announced during Summer 2022, for an expected start in October of the same year. The winning airlines would operate the routes for a total of 9 months, until July 2023, with the financial support of the Finnish government. On 5th September 2022, Traficom announced that the five domestic routes will be operated by Finnair. During the previous tender (from March 2021 to July 2022), three airlines were operating the routes: Amapola Flyg to JOE, Danish Air Transport to KAJ and Nyx Air to KOK-KEM.

After winning the tender, however, Finnair announced to the Finnish newspaper Yle that the carrier would not be willing to operate these provincial routes without the financial support granted. An airline's representative stated Finnair does not have suitable planes for these routes, meaning small enough planes. Also Danish Air Transport, who previously operated on the Finnish PSO, declared not to be interested in operating the routes without any government support (Takalo & Markkula 2022).

In the case of these routes, the implementation of electric aircraft could be very beneficial. The utilization an aircraft like *ES-30* or *Alice* on these low-frequency, low-demand routes would have a substantial financial advantage for the airline: with a lower seat offering, demand spoilage is avoided, maximizing revenue for the operating airline;

On the invitation to tender, Traficom also notes the average number of passengers per flight; additionally, the authority requests a minimum seating capacity of the plane for every route, as well as the schedule to follow (Traficom 2022).

Destination	JOE	JYV	KAJ	KEM-KOK
Passengers	17	5	29	14 (combined)
Min capacity requested	42	21	42	42
Load factor (estimate)	40%	24%	69%	33%

Table 9. Demand, capacity requested and estimated load factor on PSO routes. Source: Traficom 2022.

With the exception of KAJ, the routes' passenger results are way lower compared to the capacity required by Traficom's tender, with load factors that would never result into profitability for the operator. This is a clear demonstration of how PSO routes, despite representing a vital service for peripherical regions, are not financially viable for airlines.

The following considerations can be made on the case:

- Due to the very low numbers, JYV would be a suitable mission for Alice.
- KAJ represents a case similar to what has been discussed in Chapter 6.3: to meet the "higher" demand, the city pair could be served more times during the day, concurrently to HEL's Finnair time banks.
- On the HEL-KEM-KOK triangle route, both Alice and ES-30 could be a good fit. However, ES-30 could not operate the HEL-KEM segment, leaving KEM connected only by one stop.

Finnair would be a suitable operator for these routes in a scenario with electric aircraft, especially if combined with the Case 2. First, the routes would benefit from the airline's extensive network, with many convenient connections. Also, thanks to its diversified fleet, the demands and the frequencies can be adjusted and allocated to larger aircraft. For example, if there is a spillage of demand in certain frequencies of the week (for example, a Sunday evening or a Monday morning), it would be easier to allocate an ATR72 instead of ES-30.

It is also worth noting that electrifying these routes would require a strong collaboration within the airline (Finnair), the airport operator (Finavia) and the authority (Traficom).

6.5 Case 4: an example of linear network

It has been discussed in Chapter 5 that the routes of a linear network could be viable for ES-30, linking several cities on a same itinerary. As an example, it has been chosen to plan a trunk route between Stockholm-Arlanda (ARN, Sweden) and Helsinki-Vantaa (HEL, Finland), via Mariehamn (MHQ, Aland Islands – Finland) and Turku (TKU, Finland).

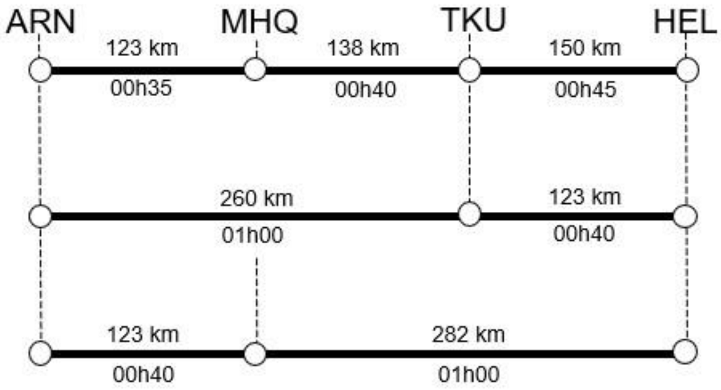

Figure 8. Stockholm to Helsinki via Mariehamn and Turku: distances and flight times.

With this route, six markets overall are served: HEL-TKU, HEL-MHQ, HEL-ARN, TKU-MHQ, TKU-ARN, MHQ-ARN. The single segments all fall within the maximum range of ES-30. The table below shows the current situation of the direct offer on these markets (excluding HEL-ARN, whose situation is described later).

<table>
<tr><th colspan="2">HEL-TKU</th><th colspan="2">HEL-MHQ</th><th colspan="2">TKU-MHQ</th></tr>
<tr><td colspan="2">6 weekly flights, Finnair
ATR72, 68 seats
408 seats/week</td><td colspan="2">4 weekly flights, Finnair
ATR72, 68 seats
272 seats/week</td><td colspan="2">5 weekly flights, Nyx Air
Saab S340, 33 seats
165 seats/week</td></tr>
<tr><td colspan="3"><i>TKU-ARN</i> <i>(starts 30th October 2022)</i></td><td colspan="3">MHQ-ARN</td></tr>
<tr><td colspan="3"><i>12 weekly flights, SAS</i>
<i>ATR72, 70 seats</i>
<i>840 seats/week</i></td><td colspan="3">11 weekly flights, Nyx Air
Saab S340, 33 seats
365 seats/week</td></tr>
</table>

Table 10. Current capacity on selected one-way markets of the potential linear network.

The current situation on the market shows a combined offering of roughly 1200 seats a week distributed between 25 weekly flights; MHQ-ARN is the most frequently served sector, with two daily flights on weekdays and one daily flight on Sundays. The segments between HEL, TKU and MHQ all represent low-demand, low-frequency services (HEL-TKU and HEL-MHQ have been discussed in Chapter 6.3).

It can be understandably argued that such network is disadvantageous on the HEL-ARN market, since the overall flight time (02h50 with two stops, 02h05 with one stop) is respectively three and two times longer than a direct flight. Also, the competition of direct flights is disproportionately larger, currently counting an average of 14 flights a day mostly operated by jets with more than 100 seats (principally Airbus A320 family and Boeing 737-800). For this reason, the target demand of this linear network should be put instead on two distinguished categories:

- Direct travellers on the segments HEL-TKU, HEL-MHQ, TKU-MHQ, TKU-ARN, MHQ-ARN;
- Connecting travellers (TKU/MHQ-HEL/ARN), feeding the hubs of HEL and ARN.

Consequently, the demand spilled from these two categories can then be recaptured on the HEL-ARN segment.

As far as intermodal competition is concerned, the routes to and from MHQ would compete directly with the ferry connections between Stockholm and Turku/Helsinki, on which air routes have a significant time-saving advantage. On the HEL-TKU segment, trains and buses travel between the two cities in a little more than two hours (Finnair itself operates some bus services between Helsinki Airport and Turku as an intermodal feeder), representing a concrete threat of substitution on the air route. Therefore, on this last segment, the operating carrier should focus mostly on the feeder traffic towards the hubs.

The figure below visualizes the target demand for each segment of the network:

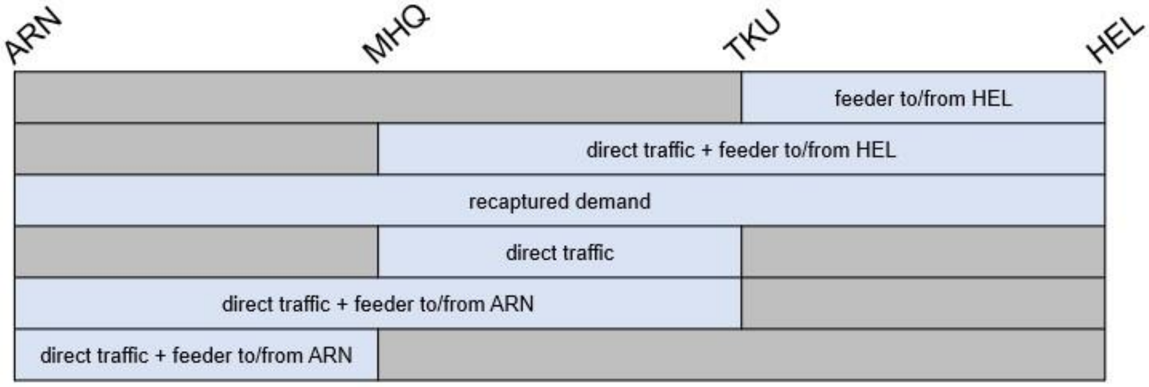

Figure 9. Characteristics of the target demand on the studied linear network.

An example of possible scheduling and aircraft planning has been shaped (*Appendix 3a*). In the model created three aircraft are used, based respectively on the two ends (HEL, ARN) and on one middle point of the network (MHQ). With three planes carrying out each three full return rotations a day, TKU and MHQ would both benefit from 9 departures a day towards ARN and HEL, offering several connection opportunities on both sides of the network.

An early departure from one end benefits the feeder traffic of the other end: while a departure from HEL at 04:25 seems unfavorable, the arrival in ARN at 06:15 helps channel the feeder traffic from TKU and MHQ towards the destinations beyond ARN hub, and same applies to the opposite direction.

Further flexibility can be given to this linear network; the operating carrier can shape the routing according to the demand, deciding to allocate more resources only on parts of the network without necessarily follow the complete routing for every mission. This possibility is examined in the *Appendix 3b*: for example, if the demand is strong enough, one extra aircraft can be allocated in favor of more direct frequencies on ARN-TKU, or it can be decided to fly only ARN-MHQ-TKU and not proceeding to HEL. Also, during the day the aircraft could operate only one sector and return back if within the range (e.g. ARN-MHQ-ARN, last row).

Lastly, it can be discussed what airlines could operate this linear network. Instinctively, the choice would go for an airline operating a hub in one of the two ends of the routing, so either SAS for Stockholm-Arlanda or Finnair for Helsinki. However, it would also be possible for a regional airline to operate the network and then sign an interline agreement with the network carriers; for example, Nyx Air or Amapola Flyg could take over this network.

6.6 Other possible scenarios for future research

As Anders Forslund, CEO of Heart Aerospace, stated during the Hangar Event in September 2022, the market for a new, small regional airliner exists; some markets and geographical areas require the existence of air services, in order to guarantee, for example, vital connections to and from bigger cities, or feeder transportation to main hubs. Some examples are shown in *Figure 11*.

Islands and archipelagos (such as Balearic Islands – *a*) represent great potential markets for electric aircraft, thanks to the often short distances, as well as to the need of be linked within each other and to the mainland, considerably saving time and emissions compared to transport by sea.

Morphologically complex countries, like Italy (*b*), would also benefit from an electrified air network. The presence of big mountain chains, along with narrow valleys, indented shores and small islands, makes it quite difficult to possess a consistent road and rail infrastructure. Also, several short feeder routes to the hubs of Milan and Rome have very often proven to be financially unstable because of the lack of suitable aircraft. A 30-seater aircraft would easily guarantee a good, time-cutting alternative to trains and buses in central Italy or in the Alpine region. The same applies to the domestic network in Austria.

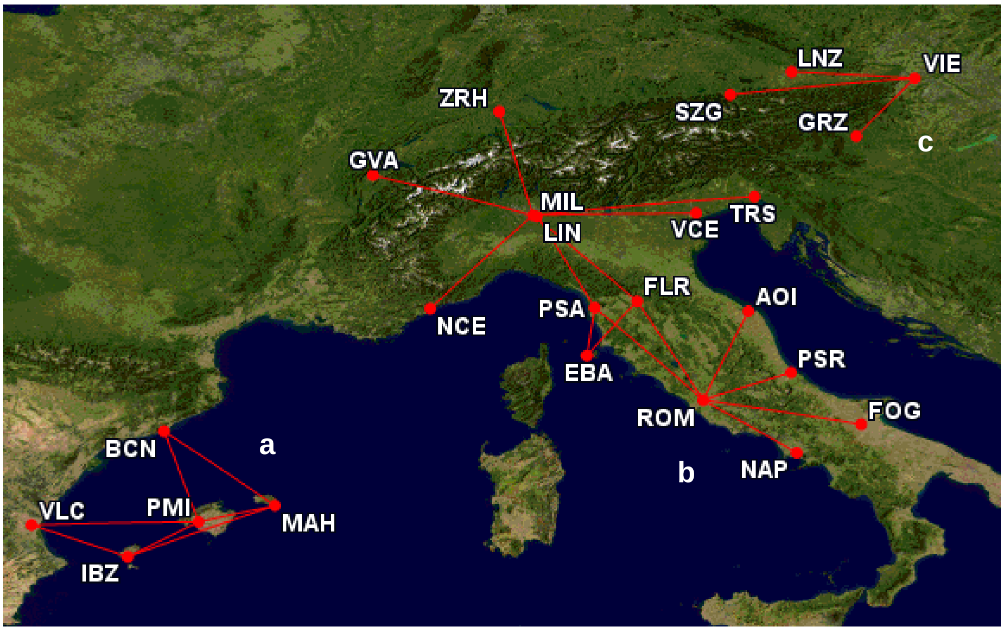

Figure 11. Examples of electrifiable routes within Continental Europe: Balearic Islands (a), Italy (b), Austria (c).

7 Discussion

This research aimed at exploring the possibility of implementing electric aircraft into the airline business, understanding which networks, routes, business models and strategies would be suitable for them and what could be some potential markets in a first stage.

The results of the study show that, commercially, electric aviation can become a potential solution for the industry, and at least on the first stages it can represent a valid replacement of fuel-powered jets on regional networks. First of all, it will be a great step forward in the effortless work on sustainability made recently;. This can for sure be a starting point for further development.

Network carriers based on hub-and-spoke networks can be more cost-effective on regional and domestic routes with low demand and low capacity with the utilization of smaller aircraft; consequently, mainline carriers' subcontractors would also benefit from a more balanced network in terms of yield and capacity. Regional airlines would definitely find in these aircraft a suitable solution to serve remote areas of their networks more effectively.

Europe proves to be a good testing ground for the implementation of small networks powered by electric aircraft, as several markets fall directly into the targets of ES-30 and Alice: it is shown in the examples of Helsinki-Tallinn, as well as in selected PSO routes all over the continent. Also, the idea of an "electric hub" to connect the Arctic region sounds promising.

The success of electric aircraft and a smooth transition towards their implementation, however, depends on many factors: among others, appropriate infrastructure should be implemented in the airports, manufacturers and companies will need to invest on further research, more data about the profitability of charging stations and batteries are needed. Being a very young business, electric aviation needs to mature into a potential reality for the near future. In order to let this concept become reality, the duties and the needs of all the stakeholders involved need to be firmly taken into consideration. This step is possible only with a strong collaboration between all the parts involved within the industry.

Many steps of development will surely need to be made, before getting to the processes of network planning: however, as mentioned in the introduction, the aim of the author is to trigger further awareness and research on the topic, as the drive of the aviation industry towards sustainability is now an urgent priority and not anymore a mere trend. This study can be also seen as a logical prediction of how future airline operations could look like.

8 Conclusion

In a business environment where the drive to profitability and the urgency for sustainable alternatives are becoming the priority, it is crucial for the aviation industry to work towards concrete solutions. Understanding how new technologies can help the sector both environmentally and financially and how they can be integrated into the current states is a good opening move towards this direction.

From an academic perspective, this research can be seen as an *exercice de style*, where the basic rules of network planning and yield management (in here combined with the preliminary data about electric aircraft) are practically applied to real-life cases. Of course, not having access to official sensitive data and the professional tools used in the industry, the accuracy of the case studies cannot be the one reached in the planning departments of an airline; this research is based on the analysis and the study of the information accessible and the observation of the airport environment.

Writing this thesis has given a more proper understanding of the state of electric aviation, the future goals and aspirations of this niche sector, as well as a larger overview of network management, expanding the knowledge of what has been studied during the Aviation Business curriculum.

Conducting the literature review has been in some parts intricate, given the complexity of doing research in a new field of study; also, keeping up with the steady flow of new information coming almost on a daily basis has been an engaging challenge. However, designing the case studies has been certainly rewarding.

It would be a privilege to see these same cases becoming reality sooner or later, hoping for the joint effort of the stakeholders to move forward, towards an exciting, greener future for the industry.

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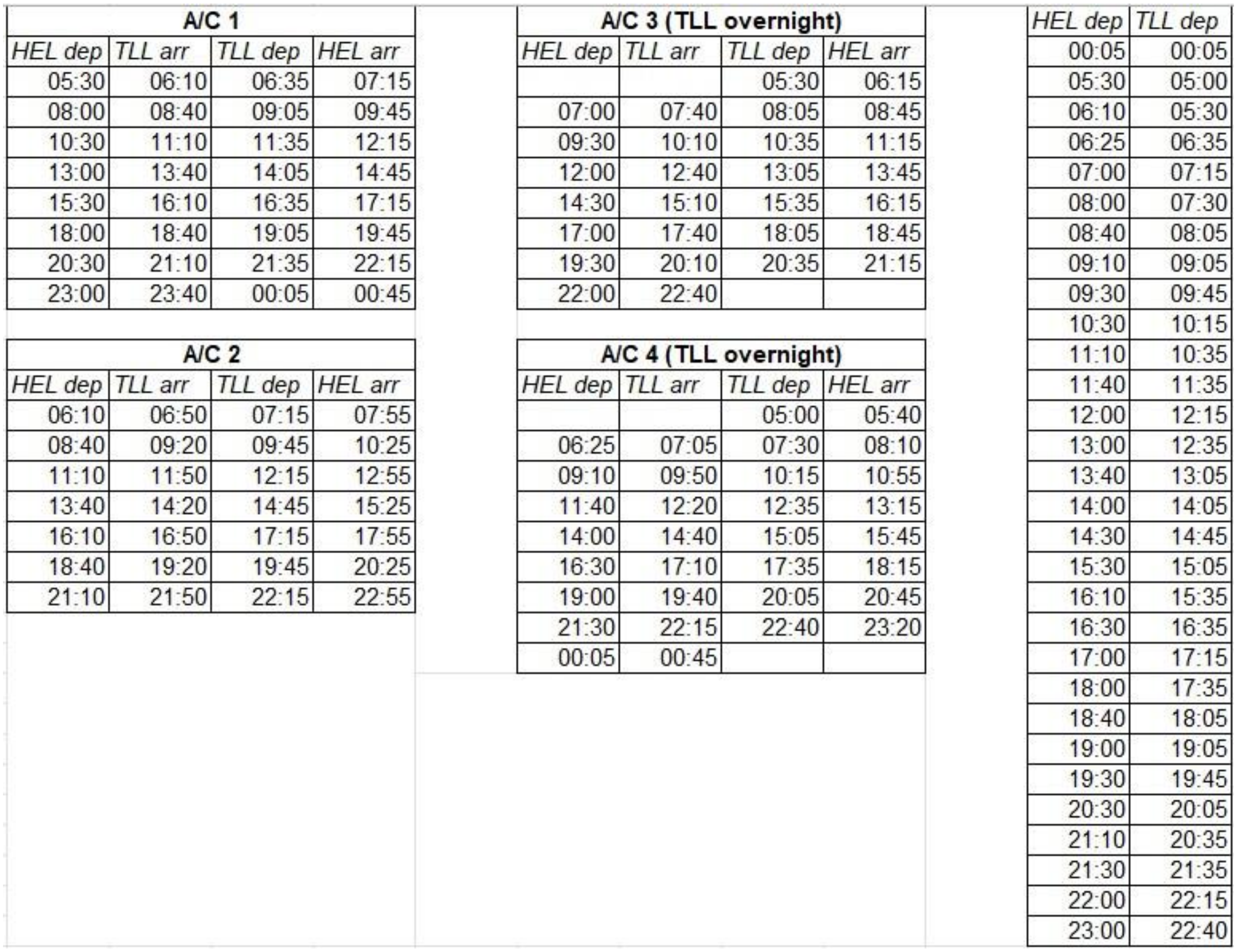
Appendices

Appendix 1. Wideroe’s PSO network

(Source: Wideroe official website)

Appendix 2. Tentative scheduling on Case 2, Finnair network (Chapter 6.3)



A/C 1			
HEL dep	*TLL arr*	*TLL dep*	*HEL arr*
05:30	06:10	06:35	07:15
08:00	08:40	09:05	09:45
10:30	11:10	11:35	12:15
13:00	13:40	14:05	14:45
15:30	16:10	16:35	17:15
18:00	18:40	19:05	19:45
20:30	21:10	21:35	22:15
23:00	23:40	00:05	00:45

A/C 2			
HEL dep	*TLL arr*	*TLL dep*	*HEL arr*
06:10	06:50	07:15	07:55
08:40	09:20	09:45	10:25
11:10	11:50	12:15	12:55
13:40	14:20	14:45	15:25
16:10	16:50	17:15	17:55
18:40	19:20	19:45	20:25
21:10	21:50	22:15	22:55

A/C 3 (TLL overnight)			
HEL dep	*TLL arr*	*TLL dep*	*HEL arr*
		05:30	06:15
07:00	07:40	08:05	08:45
09:30	10:10	10:35	11:15
12:00	12:40	13:05	13:45
14:30	15:10	15:35	16:15
17:00	17:40	18:05	18:45
19:30	20:10	20:35	21:15
22:00	22:40		

A/C 4 (TLL overnight)			
HEL dep	*TLL arr*	*TLL dep*	*HEL arr*
		05:00	05:40
06:25	07:05	07:30	08:10
09:10	09:50	10:15	10:55
11:40	12:20	12:35	13:15
14:00	14:40	15:05	15:45
16:30	17:10	17:35	18:15
19:00	19:40	20:05	20:45
21:30	22:15	22:40	23:20
00:05	00:45		

HEL dep	*TLL dep*
00:05	00:05
05:30	05:00
06:10	05:30
06:25	06:35
07:00	07:15
08:00	07:30
08:40	08:05
09:10	09:05
09:30	09:45
10:30	10:15
11:10	10:35
11:40	11:35
12:00	12:15
13:00	12:35
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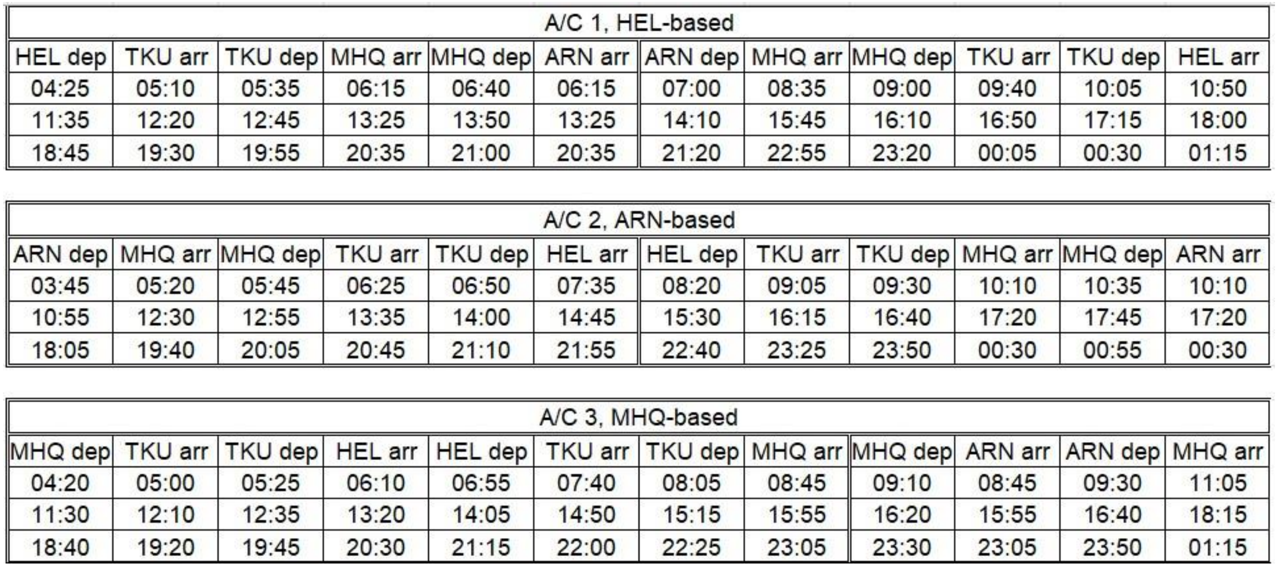
14:00	14:05
14:30	14:45
15:30	15:05
16:10	15:35
16:30	16:35
17:00	17:15
18:00	17:35
18:40	18:05
19:00	19:05
19:30	19:45
20:30	20:05
21:10	20:35
21:30	21:35
22:00	22:15
23:00	22:40

Schedule example of fully electrified HEL-TLL market.

Appendix 3. Tentative scheduling on Case 4, Linear Network (Chapter 6.5)



A/C 1, HEL-based

HEL dep	TKU arr	TKU dep	MHQ arr	MHQ dep	ARN arr	ARN dep	MHQ arr	MHQ dep	TKU arr	TKU dep	HEL arr
04:25	05:10	05:35	06:15	06:40	06:15	07:00	08:35	09:00	09:40	10:05	10:50
11:35	12:20	12:45	13:25	13:50	13:25	14:10	15:45	16:10	16:50	17:15	18:00
18:45	19:30	19:55	20:35	21:00	20:35	21:20	22:55	23:20	00:05	00:30	01:15

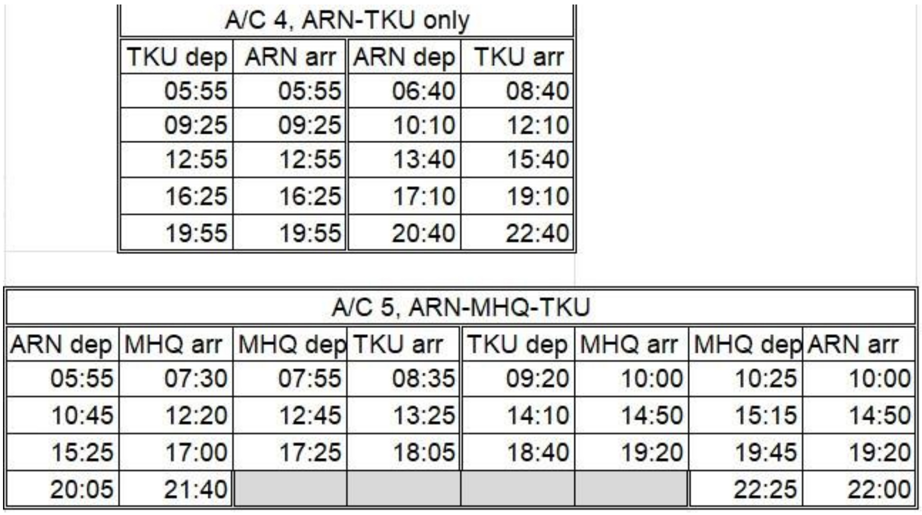
A/C 2, ARN-based

ARN dep	MHQ arr	MHQ dep	TKU arr	TKU dep	HEL arr	HEL dep	TKU arr	TKU dep	MHQ arr	MHQ dep	ARN arr
03:45	05:20	05:45	06:25	06:50	07:35	08:20	09:05	09:30	10:10	10:35	10:10
10:55	12:30	12:55	13:35	14:00	14:45	15:30	16:15	16:40	17:20	17:45	17:20
18:05	19:40	20:05	20:45	21:10	21:55	22:40	23:25	23:50	00:30	00:55	00:30

A/C 3, MHQ-based

MHQ dep	TKU arr	TKU dep	HEL arr	HEL dep	TKU arr	TKU dep	MHQ arr	MHQ dep	ARN arr	ARN dep	MHQ arr
04:20	05:00	05:25	06:10	06:55	07:40	08:05	08:45	09:10	08:45	09:30	11:05
11:30	12:10	12:35	13:20	14:05	14:50	15:15	15:55	16:20	15:55	16:40	18:15
18:40	19:20	19:45	20:30	21:15	22:00	22:25	23:05	23:30	23:05	23:50	01:15

3a. Example of full linear network operated by three aircraft.



A/C 4, ARN-TKU only

TKU dep	ARN arr	ARN dep	TKU arr
05:55	05:55	06:40	08:40
09:25	09:25	10:10	12:10
12:55	12:55	13:40	15:40
16:25	16:25	17:10	19:10
19:55	19:55	20:40	22:40

A/C 5, ARN-MHQ-TKU

ARN dep	MHQ arr	MHQ dep	TKU arr	TKU dep	MHQ arr	MHQ dep	ARN arr
05:55	07:30	07:55	08:35	09:20	10:00	10:25	10:00
10:45	12:20	12:45	13:25	14:10	14:50	15:15	14:50
15:25	17:00	17:25	18:05	18:40	19:20	19:45	19:20
20:05	21:40					22:25	22:00

3b. Examples of additional capacity on portions of the linear network.