FAIR PROMOTES ELECTRIC AVIATION

ELECTRIC AVIATION 2022

REGIONAL PREREQUISITES FOR ELECTRICAL AVIATION

EUROPEAN UNION

Interreg Botnia-Atlantica

European Regional Development Fund

BIOFUEL REGION & MIDTSKANDIA - PROGRESS THROUGH PROJECTS

BioFuel Region is a member owned non-profit organization working for a well-developed bioeconomy and a low carbon vehicle fleet by initiating, coordinating, and collaborating on project.

MidtSkandia is a Nordic border committee between Nordland and Västerbotten, that focus on cross-border cooperation through development projects and communication.

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TABLE OF CONTENTS

1. INTRODUCTION

1.1 AIM

The ambition of this report is to support airports and airport owners interested in developing electric aviation and in investing in charging infrastructure at airside.

The focus is exclusively on battery driven aircraft. It is not uncommon to include hydrogen and fuel-cell solutions under the umbrella of electric aviation, but that is not the case in this report.

1.2 WHY ELECTRIC AVIATION?

In this sparsely populated region, the Kvarken-Nordland region shown in Figure 1, there is a lack of good east-west transport communications. Moreover, there are a sea between Finland and Sweden and a mountain range between Sweden and Norway. This makes regional aviation an interesting alternative for connecting people within the region. Even though the area is sparsely populated, people live far apart, and the landscape has natural barriers, the region still has a collective population more than one million people who could be connected through electric aviation.

In comparison with existing fossil fuel-based options, electric aviation is a more sustainable alternative and might be an optimal solution for developing regional travel. The required infrastructure is cheap for society compared with rail infrastructure, since airports are already in place and only need to be augmented with charging infrastructure.

This report has been developed within the FAIR project and funded by Interreg Botnia-Atlantica in 2022. It should be cited as:

> Smedberg, A. et al., (2022). *Electric aviation 2022. Regional prerequisites for electrical aviation.* BioFuel Region and MidtSkandia.

The report can be downloaded at the website for the Kvarken Council.

2. BACKGROUND

Electric aviation is in a strong phase of development, and there are many development projects of aircraft and electrical take-off and landings (eVTOLs) globally. The report "Technological overview" from 2021 includes the state of battery development, the development of aircraft and infrastructure at airside and regulations.[1] It seems likely that it will be possible, both technically and infrastructurally, to travel by electric aircraft within five to 10 years. The technical challenges will not be the bottleneck for implementing the aviation market. The development of energy carriers will probably allow 50-passenger aircraft with a range of 300 km by 2030.

Currently, though, there no standard in place for charging infrastructure, making it difficult for airports to foresee necessary improvements to ground infrastructure. Another obstacle for aircraft developers is the certification process, which is complicated, time-consuming and costly even for aircraft with traditional fossil-based propulsion. The new challenges of electrical propulsion may make it even more challenging.

2.1 CURRENT AIR TRAFFIC IN THE REGION

As of today, air travel patterns in the Kvarken-Nordland region resemble the hub and spoke model with almost all air routes north-south and to the capitals (Figure 1). There are currently no air routes between the countries or between two destinations within the Finnish and Swedish part of the region. This is true even though there are two major natural barriers preventing time efficient land travel in the programme area: the Kvarken strait between Finland and Sweden and the Scandinavian mountains between Sweden and Norway. However, Norway has existing air routes in the Nordland region. These regional routes are operated using smaller airplanes and are included in Norway's network for Short Take-Off and Landing (STOL). Interestingly, the border between Sweden and Norway is the outer border for the European Union, which may sometimes be a challenge but also an opportunity.

[1] Norberg, I., Oja, S. and Smedberg, A. Electric aviation 2021. Technology overview. BioFuel Region (2021) https://www.kvarken.org/projekt/electric-aviation-2021-technology-overview/

2.2 AVIATION AND ENVIRONMENT

In many respects, national goals and strategies show that electric aviation is still in its early phase of development. The countries in the region are all working with these questions, but there are quite big differences in how far they have come.

Internationally, in 2008 the aviation industry reached the first agreement of emission global targets by 2050, when industry leaders came together at ATAG's (Air Transport Action Group) Aviation & Environment Summit and signed the "Commitment to Action on Climate Change". These targets were short-, mid- and long-term targets and were to be followed up by the UN organisation ICAO (International Civil Aviation

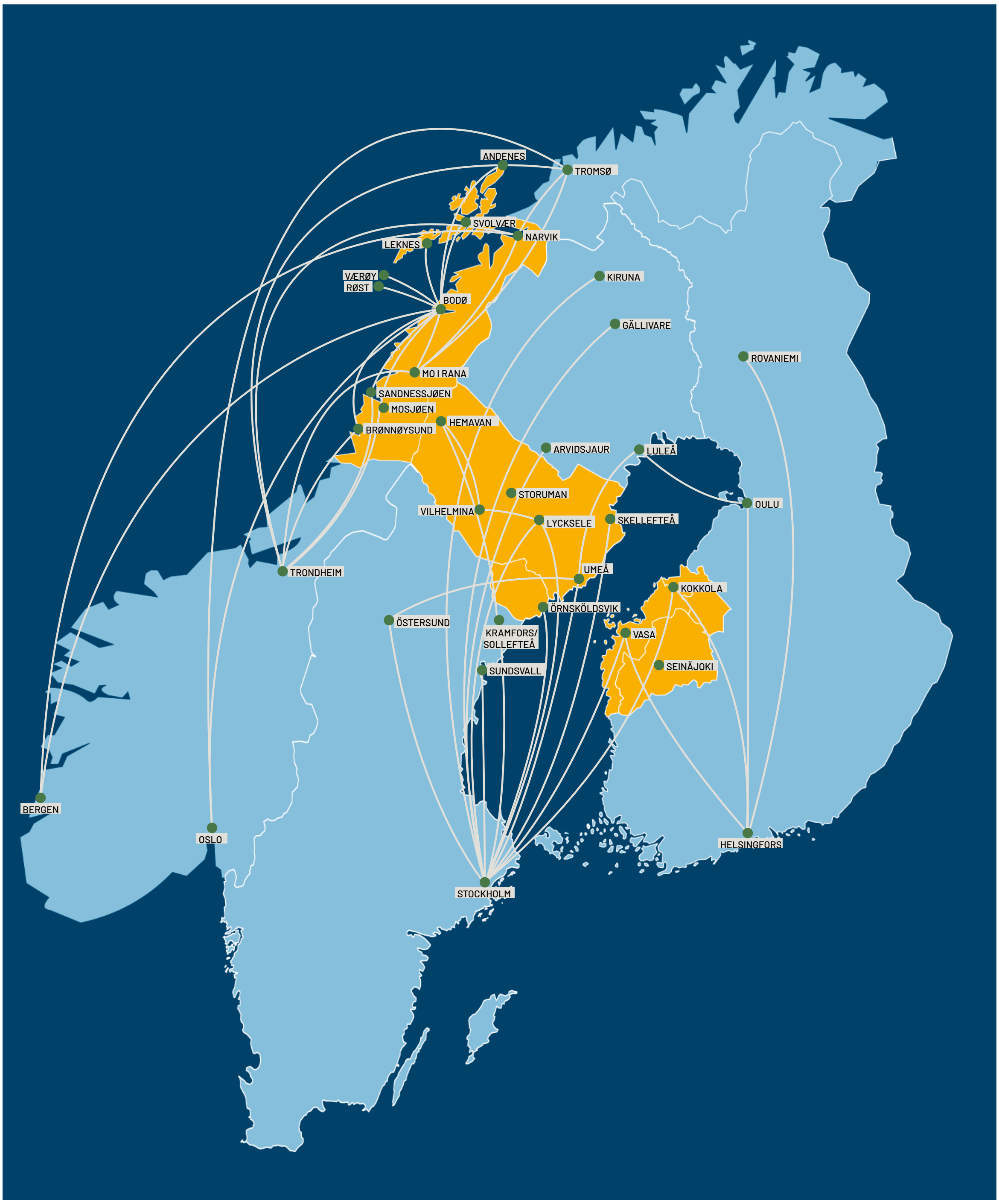

Figure 1. Current routes in Norway, Sweden and Finland.

Organization). By 2050, the goal was to have reduced CO_2 emissions by 50% in absolute numbers of 2005 levels.[2] Since then, these targets have been revised and altered. The new "Net zero carbon 2050 resolution" was passed by the member airlines in IATA (The International Air Transport Association) at the 77th Annual General Meeting in Boston on 4 October 2021. In this resolution, the members committed to achieving net zero carbon emissions for their operations by 2050.[3]

> "In the IATA's *Net zero carbon 2050 resolution* the members commiting to achive net zero carbon emissions for their operations by 2050"

There is also a hope that ICAO, which falls under the UN and has its own targets, will adopt new, more progressive targets in line with those of IATA when they have their assembly in the autumn of 2022. ICAO's current target, adopted in 2019, is a 2% annual fuel efficiency improvement through 2050 and carbon neutral growth from 2020, established at the 37th Assembly in 2010.[4]

The EU has launched the *European Green Deal*, which includes the *Fit for 55 directives* that set up targets for 2030 and 2050. The purpose of the Fit for 55 package is to translate the Green Deal ambitions into legislation.[5] By accepting the legislation, the EU has committed member states to reduce net greenhouse gas emissions by at least 55% by 2030, when compared with 1990 levels. Within the Fit for 55 directive, there have been both revisions of existing legislation and development of new legislation. The existing legislation of infrastructure for alternative fuels (AFIR) includes suggestions on requirements for electrical connections for standing aircraft at airports.[6] The new legislation on sustainable aviation fuels "*ReFuel Aviation*" proposes that from 2025, fuel companies will be obliged to gradually increase the volume share of sustainable aviation fuel (SAF) in aviation fuel. By 2025, there will be 2% SAF in volume share, by 2030 5%, 2035 20% and up to 63% by 2050. There are also sub quotas for RFNBO (renewable fuels non biological origin).[7]

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[2] Föreningen Svenskt flyg (2018). Färdplan för fossilfri konkurrenskraft: Flygbranschen. p. 15. https://www.svensktflyg.se/wp-content/uploads/2018/04/F%C3%A4rdplan-f%C3%B6r-fossilfri-konkurrenskraft-flygbranschen.pdf

[3] https://www.iata.org/contentassets/b3783d24c5834634af59148c718472bb/factsheet_netzeroresolution.pdf Accessed 3 June 2022.

[4] https://www.icao.int/environmental-protection/pages/climate-change.aspx Accessed 3 June 2022.

[5] https://www.consilium.europa.eu/sv/policies/green-deal/ Accessed 10 June 2022.

[6] Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU of the European Parliament and of the Council. https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX-:52021PC0559

[7] Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on ensuring a level playing field for sustainable air transport. https://ec.europa.eu/info/sites/default/files/refueleu_aviation_-_sustainable_aviation_fuels.pdf

2.3 FINLAND

2.3.1 National goals

Finland has set 2035 as the target for reaching carbon neutrality and soon after becoming carbon negative.[8] To the best of our knowledge, there are no national strategies for how to reduce carbon emissions from aviation or for a green transition within aviation. However, Finland has initiatives for this within the aviation sector. In 2018, an agreement of cooperation was signed between Finavia and Helsinki Electric Aircraft Association to expand knowledge on electric aviation and, in extension, developing airports.[9] The first electric airplane to take off in Finland was the two-seater Pipistrel Alpha Electro on 31 June 2018.[10]

2.3.2 Who owns the airports?

In Finland, the absolute majority of the airports are owned and operated by Finavia, 21 of totally 24 airports, who also has the task of developing them and operating the nationwide traffic control system. One of the three other airports is owned by a municipality and the other two are owned by foundations and have no regular traffic.[11]

By operating nearly all airports in Finland through the state-owned Finavia, all but three airports are part of a single network that in turn consolidates into a single unit. This allows cross-subsidizing airports while still complying with EU directives and thus maintaining the network of airports. And in addition to this, Finavia has signed agreements with the Armed Forces regarding the use of 10 airports at cost price.[12]

Within the Kvarken region in Finland, the airports in Vasa and Karleby/Jakobstad are organised through Finavia while Seinäjoki airport is organised through a foundation.

2.4 NORWAY

2.4.1 National goals

Norway has set one of the world's most ambitious targets by stating that all short domestic flights will be electrified by the year 2040. Avinor's former CEO Dag Falk-Petersen believe that all flights up to 1.5 hours can be operated with fully electric planes. A first step towards this is an upcoming procurement to test a commercial route flown with a small electric plane with 19 seats, starting in 2025.[13] However, the 2025 date has been pushed back since there will not be a market certified and commercially ready aircraft by then. The revised target is 2026 when Widerø, in cooperation with Rolls-Royce, aims to have a 9-seat P-volt in service.[14]

The Ministry of Transport and Communications has commissioned Avinor and the Civil Aviation Authority to develop proposals for a programme for phasing in electrified aircraft in Norway. The proposal suggests that the first ordinary domestic scheduled flights may be electrified by 2030: "*Our recommendation is that Norway should be one of the main arenas in the world for electrification of aviation*".

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[8] https://valtioneuvosto.fi/en/marin/government-programme/carbon-neutral-finland-that-protects-biodiversity Accessed 2 May 2022.

[9] https://www.finavia.fi/en/newsroom/2018/finavia-board-finance-testing-and-development-first-electric-aircraft-finland Accessed 2 May 2022.

[10] https://www.finavia.fi/en/newsroom/2020/finavia-speed-introduction-electric-aircraft-finland Accessed 2 May 2022.

[11] Trafikanalys (2019) Flygplatser i fokus. PM 2019:6. p. 36. https://www.trafa.se/globalassets/pm/2019/pm-2019_6-flygplatser-i-fokus.pdf

[12] Trafikanalys (2019) Flygplatser i fokus. PM 2019:6. p. 36–37. https://www.trafa.se/globalassets/pm/2019/pm-2019_6-flygplatser-i-fokus.pdf

[13] Avinor (2020). Bærekraftig og samfunnsnyttig luftfart Rapport 4. October 2020. p. 28.

[14] https://www.rolls-royce.com/media/press-releases/2021/11-03-2021-rr-and-tecnam-join-forces.aspx; https://www.electrive.com/2021/03/13/zero-emission-aviation-to-take-off-in-norway-from-2026/ Accessed 7 June 2022.

Norway is dependent on aviation, and for large parts of the country aviation is a crucial part of the public transport services. According to Avinor and the Civil Aviation Authority's assessment, it is particularly important for Norway to have concrete and time-specific goals for implementation and emission reductions. The goal should be to be a driving force and an arena for developing and implementing new technology.

In the new Climate Plan for 2030, the Government specifies the faster implementation of low- or zero-emission technologies and that Norway will become an international arena for testing and developing low- and zero-emission aircraft. A collaboration will continue between the European Aviation Safety Agency (EASA) and the Civil Aviation Authority to accelerate the process of phasing in electric passenger aircraft. The agreement includes technology, regulations, and facilitation. Avinor and the Norwegian Civil Aviation Authority will work together to make ground-based infrastructure and airspace available.[15]

In October 2020, Avinor published a report defining how, for the first time, Norwegian aviation has agreed on a roadmap for becoming fossil free by 2050. Concretely, this means that domestic and outbound international flights must use fossil-free fuel.[16] As the first country in the world, Norway has implemented a requirement for the use of sustainable jet biofuels. And the Norwegian parliament, Stortinget, has decided that the target will be gradually increased up to 30 per cent by 2030 (National Transportation Plan 2018–2029). The first year, 2020, the target will be 0.5 per cent. It has not yet been determined practically how to achieve the 30 per cent target.[17]

Avinor has made a promise that small, electrified aircraft will be exempt from taxes and have access to free electricity up until 2025. Avinor has also declared that they will ensure that an adequate charging infrastructure is in place by the time electrified passenger planes begun operating.[18]

2.4.2 Who owns the airports?

Avinor AS is a Norwegian state-owned company and Norway's largest owner of airports. The company operates 44 airports, of which 12 are owned by the Armed Forces. In addition, the company owns security installations of various kinds - such as radars, radio beacons, remote-controlled base stations for the aircrafts radio connection, and control centres. The 44 state airports are financed by the Avinor system as a network. This means cross-financing of operations and development of the airports, a model that has been permitted in the EU (EASA).

Most of the airports owned and operated by Avinor are not profitable. Aeronautical and non-aeronautical revenues exceed the operating costs only at the four largest airports (Oslo, Stavanger, Bergen and Trondheim). There is a significant cross-subsidisation within Avinor. More information can be found in another report from the FAIR project.[19]

[15] https://avinor.no/en/artikler/fossilfri-luftfart-innen-2050/ Accessed 22 January 2022.

[16] Avinor (2020). Bærekraftig og samfunnsnyttig luftfart Rapport 4. Oktober 2020. p. 4. https://avinor.no/globalassets/_konsern/miljo-lokal/miljo-rapporter/avinor_baerekraftsrapport_2020.pdf

[17] Avinor (2020). Bærekraftig og samfunnsnyttig luftfart Rapport 4. Oktober 2020. p. 17. https://avinor.no/globalassets/_konsern/miljo-lokal/miljo-rapporter/avinor_baerekraftsrapport_2020.pdf

[18] Avinor (2020). Bærekraftig og samfunnsnyttig luftfart Rapport 4. Oktober 2020. p. 28. https://avinor.no/globalassets/_konsern/miljo-lokal/miljo-rapporter/avinor_baerekraftsrapport_2020.pdf

[19] Solvoll, Gisle and Hanssen, Thor-Erik (2022). Public Service Obligation (PSO) as a tool for implementing flight routes operated by electric aircrafts. Nord University. Forthcoming.

The fact that airports generate a profit finance those that run a loss is referred to as the "Avinor model". The "Avinor-model" assumes that airport charges, except for the terminal navigation charge (TNC), are equal at all Avinor airports. The model provides a predictable operation of the airports as long as the company manages to generate large enough profits at the largest airports to cover the deficit at the regional airports while at the same time managing the necessary investments at the airports. As long as this is the case, the regional airports are not dependent on subsidies from their owner (the State) to be able to maintain their operations.

There are two exceptions; State and local parties are financing the development of two completely new airports in Mo i Rana and Bodø, even though these are owned by Avinor. The company does not have the finances to cover such large investments. In addition, three municipally owned airports receive subsidies from the state budget. These are Stord, Notodden and Ørlandet. Ørlandet is a military airport, but the municipality owns and operates the civilian terminal.

Commercial income from shops, tax-free sales, rentals etc. make up a large part of Avinor's income, in addition to fees for using the airport. Under normal circumstances, the Avinor network is self-financing. The pandemic, however, has obviously had a major impact on this model. This has led to large government grants to Avinor. However, the company liquidity under pressure due to the decrease in revenue.

In Nordland, there are currently 12 airports, all operated by Avinor.

2.5 SWEDEN

2.5.1 National goals

In 2018, the aviation sector developed a roadmap for fossil-free competitiveness.[20] The roadmap was initiated by Fossilfritt Sverige. It is a national initiative to make Sweden the first fossil-free welfare nation in the world. The roadmap describes how Sweden will reach the national goal of domestic fossil-free aviation in 2030 and a completely fossil-free aviation sector by 2045. Because the roadmap was produced in 2017/2018, before much of electric aviation development emerged, the focus is on biojet fuel.

Swedavia assesses and is working toward the idea that the necessary prerequisites for electrifying parts of domestic flights will be in place before or in connetion with the first electric aircraft operating from their airports.[21] The first electric aircraft with 9 to 19 passengers available on the market is estimated to have a range of around 400 km. About one third of Sweden's domestic flights are on routes up to 400 km.[22] In February 2020, Swedavia announced the adoption of a strategy for electric aviation, power supply and infrastructure at their airports. At that time, Swedavia also announced that they were planning on launching a test site for electric airplanes at Åre/Östersund Airport, which then began in October 2020.[23] The test flights will be conducted in the airspace between Åre/Östersund and Røros Airport in Norway and in collaboration with a variety of partners.[24] The long-term ambition of Swedavia is that all of their 10 airports will have sufficient infrastructure for electric airplanes.

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[20] Färdplan för fossilfri konkurrenskraft – Flygbranschen. Fossilfritt Sverige. 2020. https://www.svensktflyg.se/rapporter/fardplan-for-fossil-fri-konkurrenskraft-flygbranschen/

[21] Meeting with Swedavia 29 March 2022.

[22] https://www.swedavia.se/omstallningen/vad-branschen-gor/ Accessed 1 October 2020.

[23] https://www.swedavia.se/om-swedavia/presskontakt/swedavia-lanserar-strategi-for-elflyg—are-ostersund-redo-for-forsta-elflyget-hosten-2020/ Accessed 1 October 2020.

[24] https://www.swedavia.se/om-swedavia/swedavias-nyhetsrum/#/pressreleases/swedavia-lanserar-strategi-foer-elflyg-aare-oestersund-redo-foer-foersta-elflyget-hoesten-2020-2972702 Accessed 2 October 2020.

2.5.2 Who owns the airports?

Sweden has 38 airports with regular passenger traffic (commercial or publicly procured) and an additional seven airports certified for instrument landing (ILS).[25] This gives Sweden 45 airports in total.

2.5.2.1 Governmentally owned airports

Sweden has a large State-owned airport company: Swedavia.[26] They own 10 airports: Kiruna, Luleå, Umeå, Åre Östersund, Stockholm Arlanda, Stockholm Bromma, Göteborg Landvetter, Visby, Ronneby and Malmö. Swedavia is responsible for developing these airports and has the means of financing planned investments.

For these airports to invest in infrastructure for electrification is a minor problem. Planning, financing, execution – all can be handled within the corporation.[27] Swedavia is currently planning for electrification of their airports.[28]

At the end of the day, the Swedish government is banking Swedavia. In 2010, when Swedavia was formed, there were regional airports left outside the company. These were handed over to local or regional owners, often with a lot less financial strength. This has been source of considerable debate in the Swedish aviation industry. Many of the regional airports only have traffic to airports owned by Swedavia (mainly Arlanda). As such, Swedavia benefits from fees (take off, landing, passengers) from all Swedish aviation but only keeps and supports the most profitable airports.

2.5.2.2 Regionally owned airports

The non-state-owned airports in Sweden are not a homogenous group. They differ with regarding to ownership, size, passenger volumes and so forth. The organisation for regional airports, SRF, lists 33 members.[29]

The government helps with a yearly subsidy for operations. The amount is calculated based on several factors, such as passenger volume and financial results, and is designed to cover "a part of the financial loss" the airport has.[30] The subsidies come either from the Transport Authority (around SEK 70 million) or are distributed through the regions (around SEK 40 million). The expectation is that the owner, normally a municipality, covers the rest of the funds needed to keep the airport in operation.

Within the Kvarken-Nordland region in Sweden, there is one airport in the Swedavia group owned by the state and seven airports owned by the municipality and organised through Swedish Regional Airports. Hemavan/Tärnaby Airport is owned both by the municipality (+90%) and by private parties.

Since the regional airports are primarily owned by municipalities and regions, a structural organisation that differs fundamentally from that in Finland and Norway, this can impact on how these Swedish airports can receive funding. Their owners must provide financial support to maintain operations while complying with EU regulations on public funding.

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[25] https://www.transportstyrelsen.se/sv/luftfart/flygplatser-flygtrafiktjanst-och-luftrum/Svenska-flygplatser1/ Accessed 6 March 2022.

[26] https://www.swedavia.se/ Accessed 6 March 2022.

[27] https://www.swedavia.se/om-swedavia/roll-och-uppdrag/ Accessed 5 March 2022.

[28] FAIR workshop, "*Topic: Charging of electrical aircraft*". 17 November 2022.

[29] https://www.flygplatser.se/flygplatser/ Accessed 7 March 2022.

[30] https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/forordning-20061577-om-statsbidrag-for-icke_sfs-2006-1577; https://trvfs.ea.trafikverket.se/TRVFS/pdf/2018nr001.pdf Accessed 5 March 2022.

The need for financial support from the owners has grown as aid from the state for operating expenses has decreased while new regulations have increased the cost of operations.

As of May 2017, the EU has a group exception regarding support to airports within Europe. This exception is designed for airports with at most 200,000 yearly passengers. This enables providing financial support without first securing approval from the European commission.

Swedish state owned and operated airports are not covered by the exception in the same way since they are organised within a single corporate group that makes a profit. Regional airports with over 200,000 annual passengers require an approval from the commission and falls under the Services of General Economic Interests (SGEI), a part of the state aid rules. Sweden has three regional airports approved under SGEI rules: Sundsvall, Kalmar and Skellefteå.[31]

The Swedish Transport Administration oversees and administrates state aid in place to cover part of deficits from operating costs at regional airports. This aid is divided into two categories: aid to airports with a public service obligation and aid to airports covered by the regional plan for transport infrastructure. Because of this division, one part of these funds is distributed directly to the airports through the Swedish Transport Administration and one part by the region or the country administrative board through the regional plans for transport infrastructure. The total amount is about SEK 100 million, roughly divided 70/30 between these two types of aid. It is worth noting that funding controlled by regions/country administrative boards is not earmarked for specific airports.[32]

[31] https://skr.se/skr/samhallsplaneringinfrastruktur/trafikinfrastruktur/flyg/driftstod.27424.html Accessed 8 February 2022.

[32] https://www.trafikverket.se/for-dig-i-branschen/Planera-och-utreda/finansiering/bidrag-till-kommuner-for-icke-statlig-flygplats/ Accessed 8 February 2022.

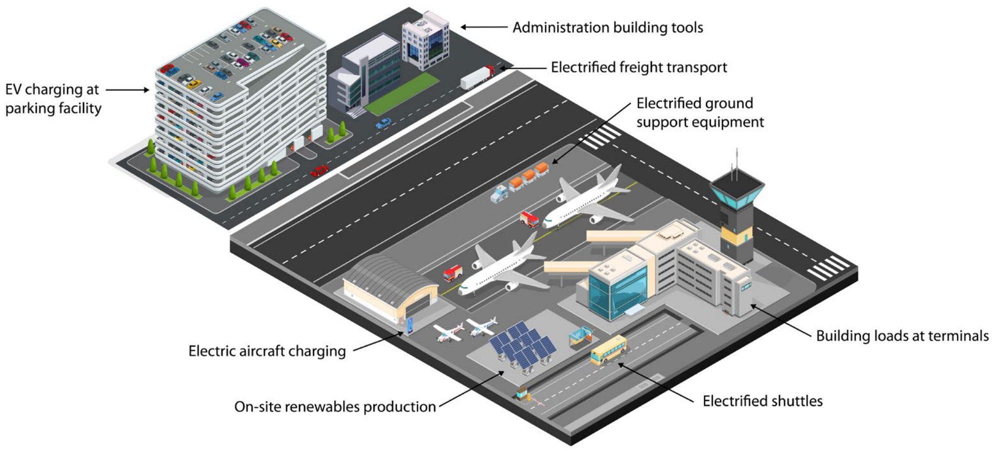
3. INFRASTRUCTURE AND NEW CONNECTIONS

Charging infrastructure for electric aircraft needs to provide a plug-in for aircraft with a certain power. In this early stage of electric aviation development and implementation, the charging stations will probably be mobile and unique for each type of aircraft. They will either be provided by the aircraft company or through a partnership with a distributor of the charging solution. Today, almost all airports in the Kvarken region have electricity contracts for sufficient power supply required by a first-generation charging station.

Several parameters must be determined to know the kind of infrastructure required at a certain airport. This need will change as aircraft and batteries are developed and demand grows. Changes in charging technology will also drive development needs. At airside, there are uncertainties about the requirements on electric aircraft, since current regulations are based on the electric instrumentation needed for regular aircraft at today's airports. For example, one suggest is that specific areas reserved for electric aircraft only will be required.

Other vehicles at an airport will also need charging capacity as the vehicle fleet, both airside and landside, is electrified. At airside, this can include machines for track preparation, fire trucks, lawn mowers, luggage transports, de-icing vehicles and tankers. On the landside, there are taxis, buses, rental cars and passenger vehicles.

A study on electric aviation in Norway states that regional electrical aircraft can operate at short field airports, which are defined by a runway of 800–1999 m.[33] Heart Aerospace's ES-19 will be able to operate on 750 m runways.[34] This is due to their size as well as the ability of electric propulsion systems to provide short bursts of power on take-off to get the aircraft airborne quicker as well as the motors' ability to be reversed and used for breaking to land in a short distance.[35] In a report by Transport Analysis, there are 83 airports in Sweden that meet these parameters. This means that besides the 39 airports having commercial air traffic today, there are 44 more potential airports.[36]



Integrated energy requirements of future airports. Illustration by Josh Bauer, NREL.

[33] Reimers, JO (2018). Introduction of Electric Aviation in Norway, Feasibility study by Green Future AS. p. 67.
[34] https://heartaerospace.com/ Accessed 16 November 2020.
[35] Fleckenstein, David and Platts, T.S. "Max" (2019). Electric Aircraft Working Group Report. Washington State Department of Transportation. p. 11.
[36] Trafikanalys (2020). Elflyg – början på en spännande resa – redovisning av ett regeringsuppdrag. Rapport 2020:12. p. 120. https://www.trafa.se/globalassets/rapporter/2020/rapport-2020_12-elflyg_borjan-pa-en-spannande-resa.pdf

3.1 CHARGING

There are three charging infrastructure solutions for an aircraft today: stationary, mobile or a battery backup solution. The electrical demand depends on how the aircraft is operated. For a quick stop at an airport, fast charging is required. For longer times on the ground, slow charging at a lower capacity can be used. Battery backups is an option for using slow charging systems with fast charging of an aircraft.

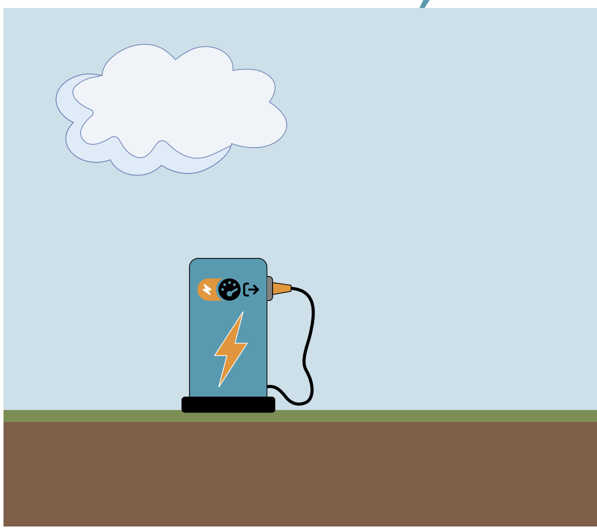
The power demand and time required for charging depends on the battery capacity, state of charge and time available to charge.

There are also some development projects looking in battery swaps, which would allow charging batteries at a slower rate. However, at this stage this technology seems to be difficult logistically, if aircraft will be operating at several airports, and financially. Another uncertainty is the certification process of the battery solution.[37]

Today, flight operators bring their own chargers to airports and connect them at a connection point (mobile chargers). In the future, the standard will probably be global and somewhere between 750 and 2000 kW.[38]

3.1.1 Stationary

Stationary charging means a charging pole mounted in the ground with the electric cables in the ground. Charging infrastructure is constantly being improved, and today, there are chargers up to 360 kW DC available from different suppliers. The technology is now robust, having been tested and proven with car infrastructure around the world. One problem has been the high power demands during charging, which can cause overheating of connection cables and the connection point on the vehicle. Moreover, charging can impact the connected electrical grid and other equipment connected to the grid.



Visualisation of stationary charger of the same design as car chargers.

Development is also occurring internationally. The Australian company ElectroAero presented their mobile DC charger with a power of 30 kW in 2019. It is able to handle 300 to 1,000 V, depending on the infrastructure at the airport. The charger is designed to connect to 3 phase 50 A and fit under the wings of most aircrafts.[39]

A company working specifically on charging infrastructure is Pipistrel, which is developing chargers for its own planes called Beta Technologies.[40] Other initiatives include for example ChargePoint, which introduced a 2-MW charge connector concept at the 2018 Uber Elevate conference. Since there are promising opportunities related to charging infrastructure, start-up level entrepreneurs are also evaluating the potential.[41]

[37] Fleckenstein, David and Platts, T.S. "Max" (2019). Electric Aircraft Working Group Report. Washington State Department of Transportation's. p. 11.

[38] Interview with Henrik Littorin, 4 September 2020.

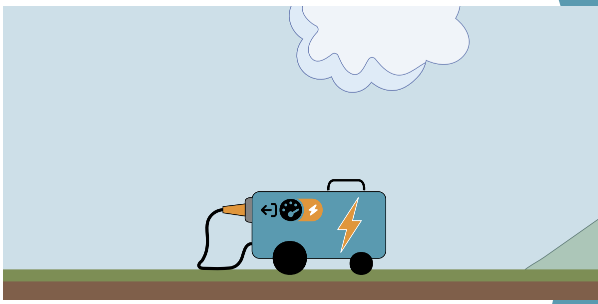
[39] https://www.electrive.com/2019/10/26/electro-aero-presents-dc-charging-solution-for-electric-aircraft/ Accessed 18 November 2020.

[40] https://www.beta.team/recharge/ Accessed 25 November 2021.

[41] Amy Schwab, Anna Thomas, Jesse Bennett, Emma Robertson, and Scott Cary (2021). Electrification of Aircraft: Challenges, Barriers, and Potential Impacts. p. 12.

3.1.2 Mobile

A mobile charger can be moved and connected to a charging pole. An example today is Pipistrel, which has their own charging infrastructure that can be connected to the grid through a mobile charging station or through an installed fast charger able to charge two or four airplanes at the same time. The charging station for two aircraft has a power of 2 x 20 kW. The time to fully charge a Pipistrel Alpha Electro airplane (60 kW power) is one hour.[42] *The Green Flight Academy* in Skellefteå uses this solution. For more about this, see "Case: Skellefteå Airport".w



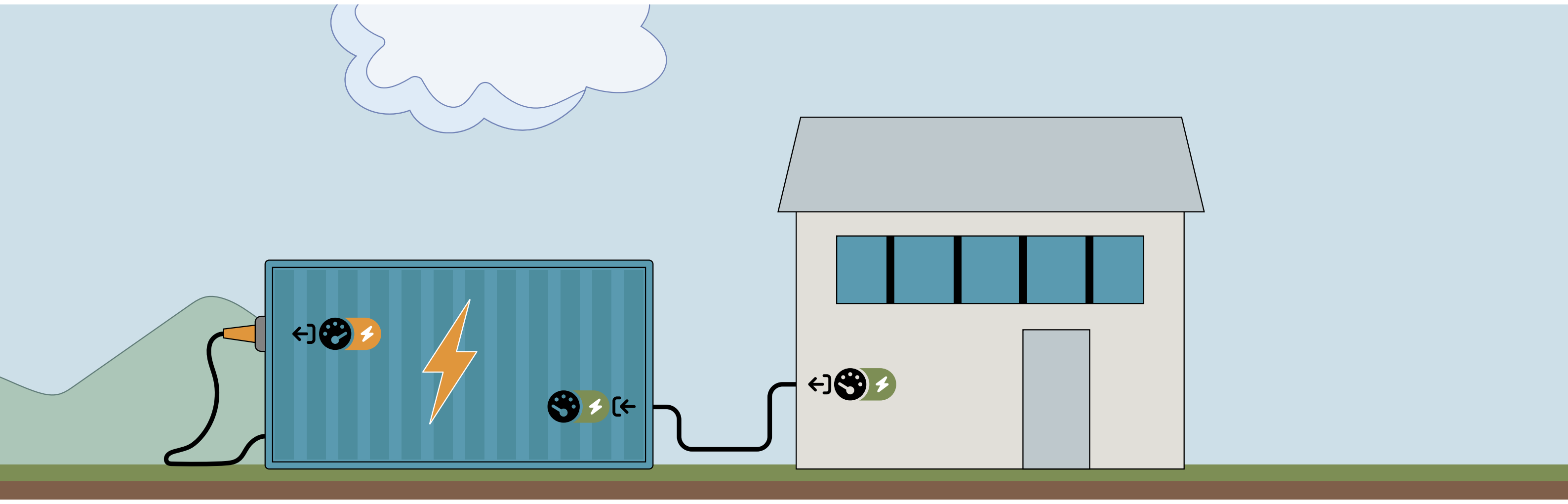
Visualisation of a mobile charger.

3.1.3 Energy storage

Battery storage is one possibility to use, which means a large battery that is slowly charged using a low power source. Then, the charged battery can be connected to the aircraft and enable a fast-charging capacity. *Mälarenergi* in Västerås has together with *Northvolt* built two battery storage systems that are available to use.[43] The purpose is to use this battery storage system for charging of electric vehicles but also to strengthen the grid for individual users close to the limit of the available capacity. It can also be used during construction of new areas where there might be a lack of power at certain times.

For an airport, a battery storage system opens for other usages except from serving as a charger for electric aircraft. It can strengthen own areas with a weak electric infrastructure or be used to sell grid services, like peak shaving or frequency.

Energy storage might be a good choice for both small and large airports. At small airports, to enable charging of few aircraft and still have a low connection power to the grid and no need to increase the grid subscription. At large airports, to be able to optimize the power usage and to enable charging within the current subscription. Another option is to take the step from being a customer to a provider on the frequency market.[44]



Visualisation of an energy storage stystem to enable fast-charging to aircraft.

[42] https://www.pipistrel-aircraft.com/aircraft/electric-flight/charging-infrastructure/ Accessed 16 November 2021.
[43] https://www.malarenergi.se/om-malarenergi/framtidens-samhalle/samarbete-med-northvolt/ Accessed 4 March 2022.
[44] https://www.svk.se/aktorsportalen/systemdrift-elmarknad/information-om-stodtjanster/ Accessed 13 May 2022.

FAIR PROMOTES ELECTRIC AVIATION

3.1.4 Status of the infrastructure today

In May 2020, the first charging station in Sweden was inaugurated at Dala Airport AB in Borlänge, with financial support from *Klimatklivet*.[45] The charging station is of the same type as fast chargers for electric cars and was installed by Hybrida in cooperation with the battery charging company CTEK.[46] In 2021, the same type of charging infrastructure with three charging stations was installed at Visby Airport with financial support from *Klimatklivet*.[47]

In 2021, Skellefteå Airport installed a connection with 1 MW. See "CASE: Skellefteå Airport".

CASE: Skellefteå Airport

Skellefteå Airport wanted to move towards becoming a fossil-free airport and a driving force for a green shift. Three tracks were identified: biofuel, electric aviation and hydrogen-based aviation. Biofuel is already available today, and hydrogen is likely to come. The airport wanted to be a forerunner and started the process of providing a charging infrastructure for electric airplanes.

The airport brought in expertise and began discussions with the municipality. The conditions were good since the municipality owns an energy company, Skellefteå Kraft, and Northvolt has a battery factory in the city. In this early stage of electric aviation, a connection point of 1 MW is sufficient and financially viable. In the coming years, charging will likely be used by several small airplanes. Parallel charging is very important to keep the planes in the air as much as possible (for financial sustainability).

The airport relied on current regulations for electrical installations for airports. The location of the chargers is physically important. There were two nearby high voltage power supplies, which facilitated installing the necessary power.

The final concept uses an airside building that includes space for measuring and test equipment and connection points for 1 MW chargers. The building is easy to mass-produce and has a roof that is shaped like an airplane wing.

The investment is seen as long term and no major income is expected. However, a flight school using 2-seated electric planes has already been established as a customer.

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[45] Klimatklivet is a subsidy from the Swedish Environmental Protection Agency for measures contributing to reducing CO2 emissions. For more information, see p. 15. https://www.naturvardsverket.se/Nyheter-och-pressmeddelanden/Satsning-pa-elektrifiering-genom-elflyg-och-elbussar-i-Klimatklivet—/ Accessed 16 November 2021.

[46] https://www.di.se/nyheter/forst-ut-i-sverige-har-kan-man-ladda-sitt-el-flygplan/ Accessed 16 November 2021.

[47] https://www.swedavia.se/visby/for-press/swedavia-fortsatter-forberedelser-for-att-ta-emot-elflyg—invigning-av-ny-infrastruktur-for-elflyg-pa-visby-airport/ Accessed 7 February 2022.

3.2 BUILDING CHARGING INFRASTRUCTURE

Initially, airports will likely be responsible for charging facilities with connection points to chargers. This type of facility needs a connection point to either the airport's own electrical grid or the local or regional electrical grid. A flight operator can invest in chargers for the flights to airports where they need to charge. Charging companies could also own and operate airport chargers. It is difficult to predict at this early stage what business model will emerge. For more information, see section 3.7 Roadmap – charging infrastructure at airports.

3.3 THE COSTS FOR INFRASTRUCTURE

The cost of getting infrastructure in place involves several things: planning, connecting electricity to a certain point, installing transformers and distributions points, and charging stations. Then, there are additional costs such as electricity subscription.

To better understand the size of required investments for building charging infrastructure at regional airports, a survey on the costs of building chargers for heavy traffic has been used for comparison.[48] This survey was conducted by the Swedish Transport Administration and concluded that it required 500 Euro/kW. A 350 kW DC charger would cost about EUR 175,000 and the double this cost for a 750 kW charger. These calculations should not be taken as absolutes since much depends on local conditions and the local electricity company's grid tariffs. The final cost also depends on whether you need to improve or rebuild the existing electrical grid.

3.4 HOW CAN THIS INVESTMENT BE FINANCED?

The European Union has the Connecting Europe Facility (CEF) fund, which finances such things as the expansion of infrastructure for distribution of alternative fuels for cars, trains, ships and aircraft. CEF's total budget for the transport sector is EUR 25.8 billion for the 2021–2027 period. Primary focuses are on infrastructure for fuel distribution in connection to the trans-European TEN-T network. However, it is also possible to receive funding for airports in connection to this network.

The Commission has also proposed linking national targets for distribution and charging stations for alternative fuels for road vehicles, ships and aircraft.[49]

Traffic analysis in Sweden examines various options for policy instruments that can drive the development of fossil-free flight. Some that can be useful for electric flight are:

- *Support for the transmission of electricity to airports for charging electric aircraft.*
- *Reimbursement for conversion of aircraft.*
- *Support for the purchase or rent of fossil-free aircraft.*

[48] Lindgren, Magnus et al. (2021). Behov av laddinfrastruktur för snabbladdning av tunga fordon längs större vägar. http://www.diva-portal.org/smash/get/diva2:1524340/FULLTEXT01.pdf p. 66.

[49] https://valtioneuvosto.fi/sv/-/diskussionsmote-30.8.2021-infrastrukturen-for-distribution-av-alternativa-branslen-ar-en-forutsattning-for-ut-slappssnala-transporter-hur-finansieras-eu-projekt- Accessed 8 February 2022.

These are good instruments. The first is aimed at airports and infrastructure. The smaller regional airports that are not part of the national airport organisations and have an important role to play in starting regional electric flight. They should be able to apply for a significant share of investments. The support should include access to electricity, possible transformers, connection costs, charging connections at airside, buildings housing chargers and battery backup. Annual support may also be needed for operating costs of smaller regional airports.[50]

3.4.1 Climate change initiative in Sweden

The Swedish Environmental Protection Agency has the subsidy "Climate change" (*Klimatklivet*), which is investment support for local and regional measures that contribute to reduced CO_2 emissions. Through smart, innovative solutions, we can move towards a more climate-smart society. This subsidy has been used to finance small chargers at airports in Sweden, as noted in the section Charging. In 2022, Klimatklivet granted support to Optand Flygplansuthyrning AB (Östersund) to purchase an electric aircraft (70% of total investment cost).[51]

3.5 ELECTRIC GRID

Today, Sweden uses 140 TWh of electricity. Svenska Kraftnät and the Swedish Energy Council forecast an increase of power consumption to around 160 TWh by 2040. Increases are mainly expected in industrial sectors, such as server facilities and battery factories, but also in electrification of industry and the transport sector.

In Finland, current power consumption is 86 TWh, of which 39 TWh is used by industry.[52] In 2040, power consumption is expected to increase to around 100 TWh.[53]

In Norway, power consumption was 126 TWh in 2020, of which 57 TWh was used by the mining and manufacturing industries. Norway is a net exporter of electricity, and in 2020 the country imported 4.5 TWh and exported 25 TWh.[54]

Region Norrbotten and Region Västerbotten have produced an analysis of the electrical grid in northern Sweden. The report clearly describes three different situations with electricity shortages. Electricity shortages arise from power deficit, shortage of electrical energy or lack of capacity in the electrical grid. When the demand for electricity at a certain time is larger than the supply, there will be a power deficit. This can happen a cold day in winter with a high use of electricity in combination with a low production caused by such issues as bad weather conditions or one or more nuclear power reactors out of service. Svenska Kraftnät has repeatedly warned about the risk of power deficits in the Swedish electricity system. Shortage of electrical energy is more of a long-term issue that can arise when the total supply of electricity is not expected to meet the total demand over time. The probability for a shortage of electrical energy in Sweden is low. Lack of capacity in the electrical grid occurs when at a certain location, for example in a city, there is not enough energy to meet demand. This is due to limitations in the electrical

[50] https://www.trafa.se/globalassets/webbinarier/klimatuppdrag/block-3-gront-flyg.pdf Accessed 10 February 2022.

[51] https://sverigesradio.se/artikel/lanets-forsta-elflygplan-snart-verklighet-det-ar-ett-stort-kliv Accessed 13 May 2022.

[52] https://energia.fi/en/newsroom/publications/energy_year_2019_-_electricity.html#material-view Accessed 24 Nov. 2020; https://www.stat.fi/tup/suoluk/suoluk_energia_sv.html Accessed 27 November 2020.

[53] Sähköntuotannon skenaariolaskelmat vuoteen 2050, 2019. https://tem.fi/documents/1410877/2132100/S%C3%A4hk%C3%B6ntuotannon+skenaariolaskelmat+vuoteen+2050+%E2%80%93+selvitys+22.2.2019/8d83651e-9f66-07e5-4755-a2cb70585262/S%C3%A4hk%C3%B6ntuotannon+skenaariolaskelmat+vuoteen+2050+%E2%80%93+selvitys+22.2.2019.pdf

[54] https://www.ssb.no/en/energi-og-industri/energi/statistikk/elektrisitet Accessed 5 May 2022.

grid, such as lack of cables, connections or transformers needed to use a certain power.[55] This type of problem has occurred in some large urban areas and has been noted by the media. The report clarifies that the regions of Norrbotten and Västerbotten have good potential for electricity-intensive investments.[56]

The energy demand from electrical aviation in this region will probably not be the bottleneck. It is more a question of fulfilling the requirements for power to charging stations. However, the initial contact with the regional airports shows that there is good potential for this and most of the airports already have sufficient power subscriptions.

3.6 CONNECTION

> "There are yet no global standard for charging an aircraft"

There is currently no global standard for charging at airports. In fact, there are no global standards when it comes to heavy duty vehicles or aircraft. But there are organisations working to establish a global standard. The biggest of them seems to be CharIn,[57] which is developing a standard called Megawatt Charging System (MCS), an extension of an initial effort called High Power Charging for Commercial Vehicles (HPCCV). According to CharIn, this standard will handle up to in excess of 2 MW and will be used for charging in the range 200-1500 V and 0-3000 A. That should be sufficient to meet the needs of heavy-duty electric vehicles with battery packs as large as around 1 MWh.[58] The standardisation organization SAE is also working on high power charging, however, there are no concrete specifications related to electric aircraft.[59]

3.6.1 Aircraft and batteries

Electric aircraft will vary in their charging needs due to different battery capacities and different possibilities to charge. Battery development is advancing rapidly, where costs and battery capacities are the most important parameters. More information on batteries can be found in the report "Electric aviation 2021, Technological overview".[60]

External parameters affect aircraft batteries and define the prerequisites for required charging electric load at airside. These external parameters are state of charge (SOC) level when arriving to the airport, SOC for departure, charging time on the tarmac (turn-around time) and the temperature of the battery.

Ideally, the battery temperature should be between 25 °C to 50 °C for optimal charging.[61] The safety SOC for the battery is set by the manufacturer and defines its ability to reach the next airport, including reserves. A battery can receive high power between the SOC of 20% and 80%. Above 80%, charging capacity is slower and the degree of efficiency is lower.[62]

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[55] https://www.ellevio.se/om-oss/Pressrum/newsroom/2019/mars/effektbrist-eller-kapacitetsbrist—eller-bade-och-vi-reder-ut-begreppen/ Accessed 30 November 2020.

[56] Region Norrbotten (2020). Regional elnätsanalys – Norrbotten och norra Västerbotten. p. 9. https://www.norrbotten.se/publika/lg/regio/2020/2020-09-03%20Regional%20eln%C3%A4tsanalys%20Norrbotten%20och%20norra%20V%C3%A4sterbotten.pdf

[57] https://www.charinev.org/

[58] https://insideevs.com/news/372749/charin-hpccv-over-2-mw-power/ Accessed 18 November 2020.

[59] ELISE/Grahn, Maria and Littorin, Henrik (2020). Elresan: Elsystemets utveckling i samband med en introduktion av elektrisk luftfart. p. 10.

[60] BioFuel Region (2021) Electric aviation 2021, Technology overview. Norberg, I., Oja, S. and Smedberg, A. p. 13. https://www.kvarken.org/projekt/electric-aviation-2021-technology-overview/

[61] Lv, S.; Wang, X.; Lu, W.; Zhang, J.; Ni, H. The Influence of Temperature on the Capacity of Lithium Ion Batteries with Different Anodes. Energies 2022, 15, 60. https://doi.org/10.3390/en15010060

[62] Kostopoulos, E.; Spyropoulos, G.; Kaldellis, J. Real-world study for the optimal charging of electric vehicles, Energy Reports, 2020, 6, 424. https://doi.org/10.1016/j.egyr.2019.12.008

FAIR PROMOTES ELECTRIC AVIATION

3.7 ROADMAP – CHARGING INFRASTRUCTURE AT AIRPORTS

This roadmap aims to help airports initiate and implement charging infrastructure at airside. Each airport has its own unique conditions for charging aircraft. There are some general steps for determining local conditions.

1. *What is the current power subscription? What electric power level is currently needed and how does this vary over the day and night and seasonally? What connection points are currently in place?*
2. *What options exist to access higher power at the airport? Start a discussion with the power supply company.*
    a. *Are there any plans to improve the power grid that you are connected to and is it even possible?*
    b. *Different types of subscriptions and costs on your grid connection.*
    c. *The time perspective for improving the electrical grid.*
3. *Is it possible to decrease the airport's use on the electrical grid and provide space for charging capacity at certain time slots?*
4. *Where are the electrical cables currently located physically in the ground? Investigate how to run an electrical cable to airside and where to place a connection, like in a small building and close to aircraft. Also consider the option of the connection point handling more than one aircraft at a time.*
5. *Adapt the charging capacity to the expected air traffic, including an eventual increase in traffic.*
6. *Other changes that might be considered are:*
    a. *Handling of arriving passengers and luggage that must pass through security before a connecting flight*
    b. *Taxi tracks for handling all the movements on the airfield*
    c. *Terminals for regional planes with charging infrastructure*
    d. *Identify a place used for charging overnight, either the same place or another (for example heated hangars) and include in calculations.*
    e. *Other increased electricity use, car or machine charging needs at the airport*
    f. *Possible disturbances to other equipment, such as communication and navigation*
    g. *Other uncertainty factors, such as fire risks*
7. *Design of the new infrastructure and cost calculations.*
8. *Financing of new electrical infrastructure. Possible financing subsides might be initiated at an earlier step, but the application process cannot start until the budgeted costs are known.*
9. *Procurement of construction and components*
10. *Construction work*

3.8 POTENTIAL ROUTES

Two different aircraft types and three different flight routes have been calculated to investigate charging infrastructure needs and possible routes for electrical flights in the region. The chosen aircraft are the 9-passenger Eviation Alice and the 19-passenger Heart ES-19. The Eviation Alice is planned for market introduction within the coming years and primarily through a FAA certification on the U.S. market. Heart Aerospace's Heart-ES19 is planned for market introduction in around five years.

The 9-seater electric aircraft Eviation Alice. ***Photo credit:*** Evation Alice.

The 19-seater ES-19 from Heart Aerospace Heart Aerospace. ***Photo credit:*** Heart Aerospace.

The parameters for the aircraft used in the calculation are shown in Table 1. The state of charge (SOC) has been set as not below 40% and not higher than 90%. This is to meet the requirement of battery reserves and the fact that the charging speed is slower after around 80% of battery charging. It has been assumed a temperature-conditioned battery with a linear charging to 90% of capacity. Uncertainties, such as wind, temperature and cooling effect on the battery, have not been included in the calculations. When calculating energy consumption for a flight, we have assumed 100% maximum power during the first 3 minutes and 10% maximum power during the last 5 minutes.

Table 1. Parameters for the two different aircraft used in the calculations.

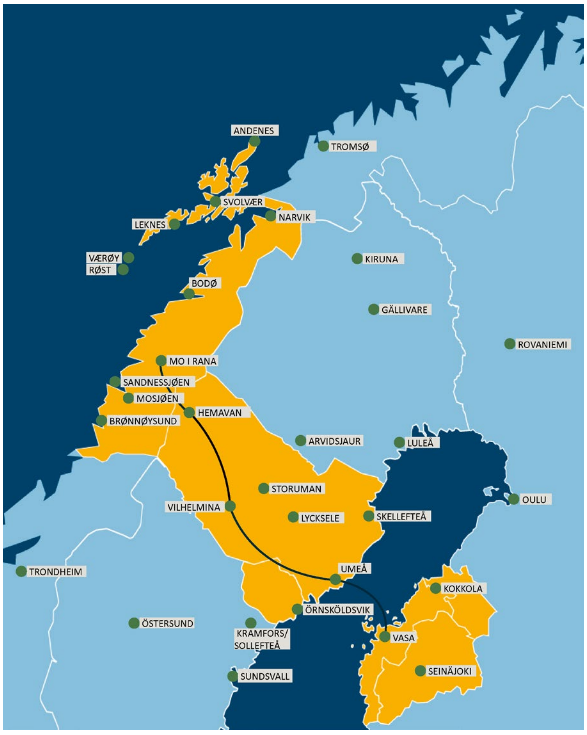
	Eviation Alice[63]	Heart ES-19[64]
Number of passengers	9-PAX	19-PAX
Cruising speed, km/h	407	300
Battery energy, kWh	820	720
Total flight time including reserves, h	2,75	1,5
Maximum power, kW	1280	1600

[63] https://www.eviation.co/aircraft/#alice-specifications Accessed 31 January 2022.

[64] A. Forslund, Heart Aerospace. https://www.youtube.com/watch?v=9wJjXBiWWJQ Time 2:02.

3.8.1 Route 1: Vasa – Mo i Rana

This flight route goes from Vasa (VAA) – Umeå (UME), on to Vilhelmina (VHM) and Hemavan (HMV) and finally to Mo i Rana (MQN). It will enable fast regional east-west travel. Today, there is no public transport between Mo i Rana and Hemavan. This route will be a complement to the buses in Sweden and will also enable fast travel over a day from Hemavan to Umeå or the other way around. Moreover, travellers from Vasa will gain a fast and convenient option for travelling both to Umeå, to the Swedish inland and mountain areas and to the ocean in Mo i Rana.



At this stage of electrical aircraft development, a trip between Vasa and Mo i Rana requires stops in Umeå, Vilhelmina and Hemavan to maintain the SOC at 40% or higher.

To be able to limit charging times to 20-30 minutes for the **19-passenger aircraft**, airports must offer between 700 and 1200 kW of maximum charging capacity, see Table 2.

Table 2. The required charging power and charging time at the different stops along the flight route Vasa (VAA) – Umeå (UME) – Vilhelmina (VHM) – Hemavan (HMV) - Mo i Rana (MQN) with a 19-passenger aircraft with a 720 kWh battery capacity. The charging power is between 700 kW and 1200 kW. SOC = State of Charge.

	Start	*Stop 1*	*Stop 2*	*Stop 3*	*Stop 4*	*Stop 5*	*Stop 6*	*Stop 7*	*Stop 8*
City	*VAA*	*UME*	*VHM*	*HMV*	*MQN*	*HMW*	*VHM*	*UME*	*VAA*
Distance, km	*0*	*110*	*195*	*152*	*70*	*70*	*152*	*195*	*110*
Time of flight, min	*0*	*22*	*39*	*30*	*14*	*14*	*30*	*39*	*22*
Charging effect at airport, kW	*1200*	*1200*	*700*	*700*	*1200*	*700*	*700*	*1200*	*1200*
Charging time at tarmac, min	*0*	*12*	*24*	*24*	*18*	*0*	*30*	*18*	*18*
Energy conumption between stops, kWh		*205*	*341*	*273*	*141*	*141*	*273*	*341*	*205*
SOC after travel, %		*71%*	*43%*	*44%*	*63%*	*80%*	*43%*	*43%*	*61%*
SOC after recharging, kWh		*648*	*587*	*594*	*720*	*579*	*648*	*648*	*720*
SOC after rechariging %	*100%*	*90%*	*81%*	*83%*	*100%*	*80%*	*90%*	*90%*	*100%*

If the larger airports have a maximum charging capacity of 700 kW and the smaller airports have 350 kW, the charging time is almost doubled at Vilhelmina and Hemavan airports, see Table 3. This considerably extends travel time between Umeå to Mo i Rana, for example, compared with having a higher charging capacity at the smaller airports. This shows the importance of having a relatively high charging capacity even at the smaller airports when the range of electric flights requires intermediate landings.

Table 3. The required charging power and charging time at the different stops along the flight route Vasa (VAA) – Umeå (UME) – Vilhelmina (VHM) – Hemavan (HMV) - Mo i Rana (MQN) with a 19-passenger aircraft with a 720 kWh battery capacity. The charging power is between 350 kW and 700 kW. SOC = State of Charge.

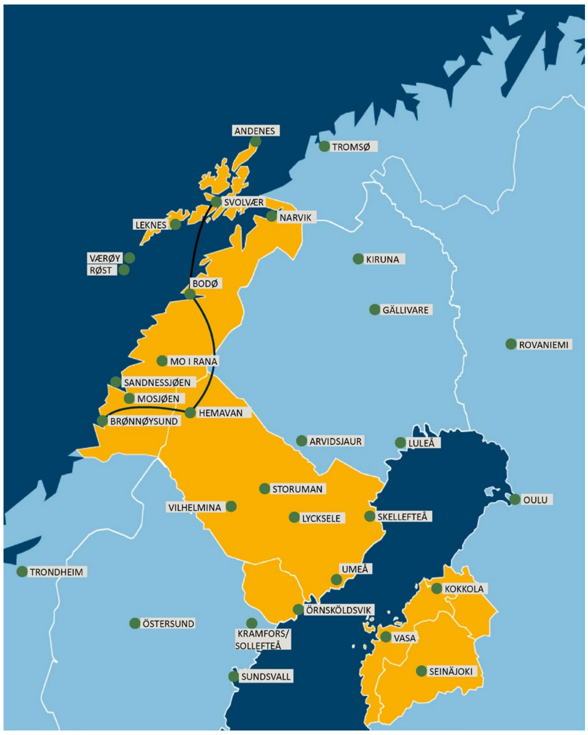
	Start	Stop 1	Stop 2	Stop 3	Stop 4	Stop 5	Stop 6	Stop 7	Stop 8
City	*VAA*	*UME*	*VHM*	*HMV*	*MQN*	*HMW*	*VHM*	*UME*	*VAA*
Distance, km	*0*	*110*	*195*	*152*	*70*	*70*	*152*	*195*	*110*
Time of flight, min	*0*	*22*	*39*	*30*	*14*	*14*	*30*	*39*	*22*
Charging effect at airport, kW	*700*	*700*	*350*	*350*	*700*	*350*	*350*	*700*	*700*
Charging time at tarmac, min	*0*	*12*	*48*	*42*	*24*	*12*	*48*	*24*	*30*
Energy conumption between stops, kWh		*205*	*341*	*273*	*141*	*141*	*273*	*341*	*205*
SOC after travel, %		*71%*	*43%*	*48%*	*58%*	*80%*	*52%*	*43%*	*53%*
SOC after recharging, kWh		*648*	*622*	*559*	*720*	*648*	*648*	*587*	*720*
SOC after recharigng %	*100%*	*90%*	*86%*	*78%*	*100%*	*90%*	*90%*	*81%*	*100%*

For the **9-passenger aircraft** shown in Table 4, the range is longer and therefore it is not necessary to charge at all stops to still maintain a SOC above 40%. In practice, it is believed that charging would take place at Vilhelmina and Hemavan to a SOC of 60-70% before take-off to Mo i Rana. For this aircraft, a charging infrastructure with a maximum power of 700 kW is enough to maintain a good flow of traffic along the travel route. However, the turnaround time in Mo i Rana will exceed 30 minutes if a 700 kW-charger is used for filling up to 100% SOC.

Table 4. The required charging power and charging time at the different stops along the flight route Vasa (VAA) – Umeå (UME) – Vilhelmina (VHM) – Hemavan (HMV) - Mo i Rana (MQN) with a 9-passenger aircraft with an 820 kWh battery capacity. SOC = State of Charge.

	Start	Stop 1	Stop 2	Stop 3	Stop 4	Stop 5	Stop 6	Stop 7	Stop 8
City	*VAA*	*UME*	*VHM*	*HMV*	*MQN*	*HMW*	*VHM*	*UME*	*VAA*
Distance, km	*0*	*110*	*195*	*152*	*70*	*70*	*152*	*195*	*110*
Time of flight, min	*0*	*16*	*29*	*22*	*10*	*10*	*22*	*29*	*16*
Charging effect at airport, kW	*700*	*700*	*700*	*700*	*700*	*700*	*700*	*700*	*700*
Charging time at tarmac, min	*0*	*0*	*6*	*6*	*42*	*0*	*12*	*6*	*42*
Energy conumption between stops, kWh		*115*	*178*	*146*	*86*	*86*	*146*	*178*	*115*
SOC after travel, %		*86%*	*64%*	*55%*	*53%*	*89%*	*72%*	*67%*	*61%*
SOC after recharging, kWh		*705*	*597*	*520*	*820*	*734*	*728*	*620*	*820*
SOC after recharigng %	*100%*	*86%*	*73%*	*63%*	*100%*	*89%*	*89%*	*76%*	*100%*

3.8.2 Route 2: Brønnøysund – Svolvær



This flight route starts in Brønnøysund (BNN) and goes to Hemavan (HMV), which is a route believed to have a future demand. In Hemavan, it is possible for travellers from Sweden and Finland to join for a continues trip to Bodø (BOO) and/or Svolvær (SVJ) in Lofoten. Generally, with this flight route is the time savings on each step as compared to travelling by car. Public transports are not available on none of the steps today, except from Bodø to Svolvær which have a flight route operated by Widerø today.

This flight route is well suited for the **19-passenger aircraft**. The distances are between 110 to 170 km and passes over sea and mountain areas. Available charging power at airports will affect travel times. Table 5 below uses a charging power of between 700 and 1200 kW. This enables a charging time of 10-20 minutes at each stop, which is suitable for a turnaround time of maximum 30 minutes. If the charging infrastructure instead was lower, between 350 to 700 kW, means charging times of 30 minutes up to 60 minutes. This might be too long for intermediate stops and therefore a higher charging power would be preferable.

Table 5. The required charging power and charging time at the different stops along the flight route Brønnøysund (BNN) – Hemavan (HMV) – Bodø (BOO) - Svolvaer (SVJ) with a 19-passenger aircraft with a 720 kWh battery capacity. SOC = State of Charge.

	Start	*Stop 1*	*Stop 2*	*Stop 3*	*Stop 4*	*Stop 5*	*Stop 6*
City	*BNN*	*HMV*	*BOO*	*SVJ*	*BOO*	*HMV*	*BNN*
Distance, km	*0*	*140*	*170*	*110*	*110*	*170*	*140*
Time of flight, min	*0*	*28*	*34*	*22*	*22*	*34*	*28*
Charging effect at airport, kW	*350*	*1200*	*1200*	*700*	*1200*	*1200*	*350*
Charging time at tarmac, min	*0*	*12*	*12*	*18*	*12*	*18*	*60*
Energy conumption between stops, kWh		*253*	*301*	*205*	*205*	*301*	*253*
SOC after travel, %		*65%*	*48%*	*53%*	*54%*	*45%*	*55%*
SOC after recharging, kWh		*648*	*587*	*591*	*626*	*648*	*720*
SOC after recharging %	*100%*	*90%*	*81%*	*82%*	*87%*	*90%*	*100%*

For the **9-passenger aircraft**, no charging is needed at the intermediate stops, see Table 6. To keep the turn-around time below 30 minutes, the charging power at Svolvaer Airport needs to be at least 700 kW. A charging power of 350 kW in Hemavan enable to increase the SOC from 50% to 63% in 18 minutes. Using 700 kW power would have resulted in an increase to 76% SOC at the same time, which is a much better choice.

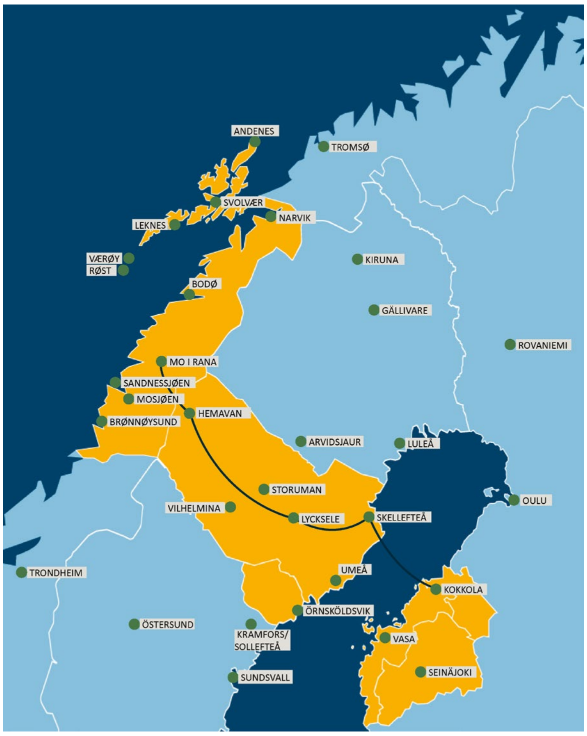
Table 6. The required charging power and charging time at the different stops along the flight route Brønnøysund (BNN) – Hemavan (HMV) – Bodø (BOO) - Svolvaer (SVJ) with a 9-passenger aircraft with an 820 kWh battery capacity. SOC = State of Charge.

	Start	*Stop 1*	*Stop 2*	*Stop 3*	*Stop 4*	*Stop 5*	*Stop 6*
City	*BNN*	*HMV*	*BOO*	*SVJ*	*BOO*	*HMV*	*BNN*
Distance, km	*0*	*140*	*170*	*110*	*110*	*170*	*140*
Time of flight, min	*0*	*21*	*25*	*16*	*16*	*25*	*21*
Charging effect at airport, kW	*350*	*350*	*700*	*700*	*700*	*350*	*350*
Charging time at tarmac, min	*0*	*0*	*0*	*24*	*0*	*18*	*60*
Energy conumption between stops, kWh		*137*	*159*	*115*	*115*	*159*	*137*
SOC after travel, %		*83%*	*64%*	*50%*	*70%*	*50%*	*46%*
SOC after recharging, kWh		*683*	*523*	*688*	*572*	*518*	*730*
SOC after recharigingl %	*100%*	*83%*	*64%*	*84%*	*70%*	*63%*	*89%*

3.8.3 Route 3: Mo i Rana – Kokkola

This flight route is along the so-called "battery belt", from Mo i Rana (MQN) to Skellefteå (SFT) via Lycksele (LYC) and further on to Karleby/Kokkola (KOK). There are already plans to start a flight route between Skellefteå and Kokkola in the autumn of 2022, based on business demand.[65]

The **19-passenger aircraft** (Table 7) is at the limit of being able to fly between Hemavan and Lycksele without falling below the safety level of 40% battery capacity left. One way of reaching Lycksele with more than 40% SOC is a longer layover in Hemavan to reach a 100% SOC. However, this is time consuming since the last 10-20% (between 80-100%) to charge the battery occurs at slower rate. Generally, a higher charging power is motivated at both Hemavan and Lycksele Airports to improve travel times. Depending on the turnaround time at Kokkola/Karleby Airport, a higher charging capacity is preferable.



[65] https://svenska.yle.fi/a/7-10014604 *Visited 29 Mar. 2022.*

Table 7. The required charging power and charging time at the different stops along the flight route Mo i Rana (MQN) – Lycksele (LYC) – Skellefteå (SFT) – Kokkola (KOK) with a 19-passenger aircraft with a 720 kWh battery capacity. SOC = State of Charge.

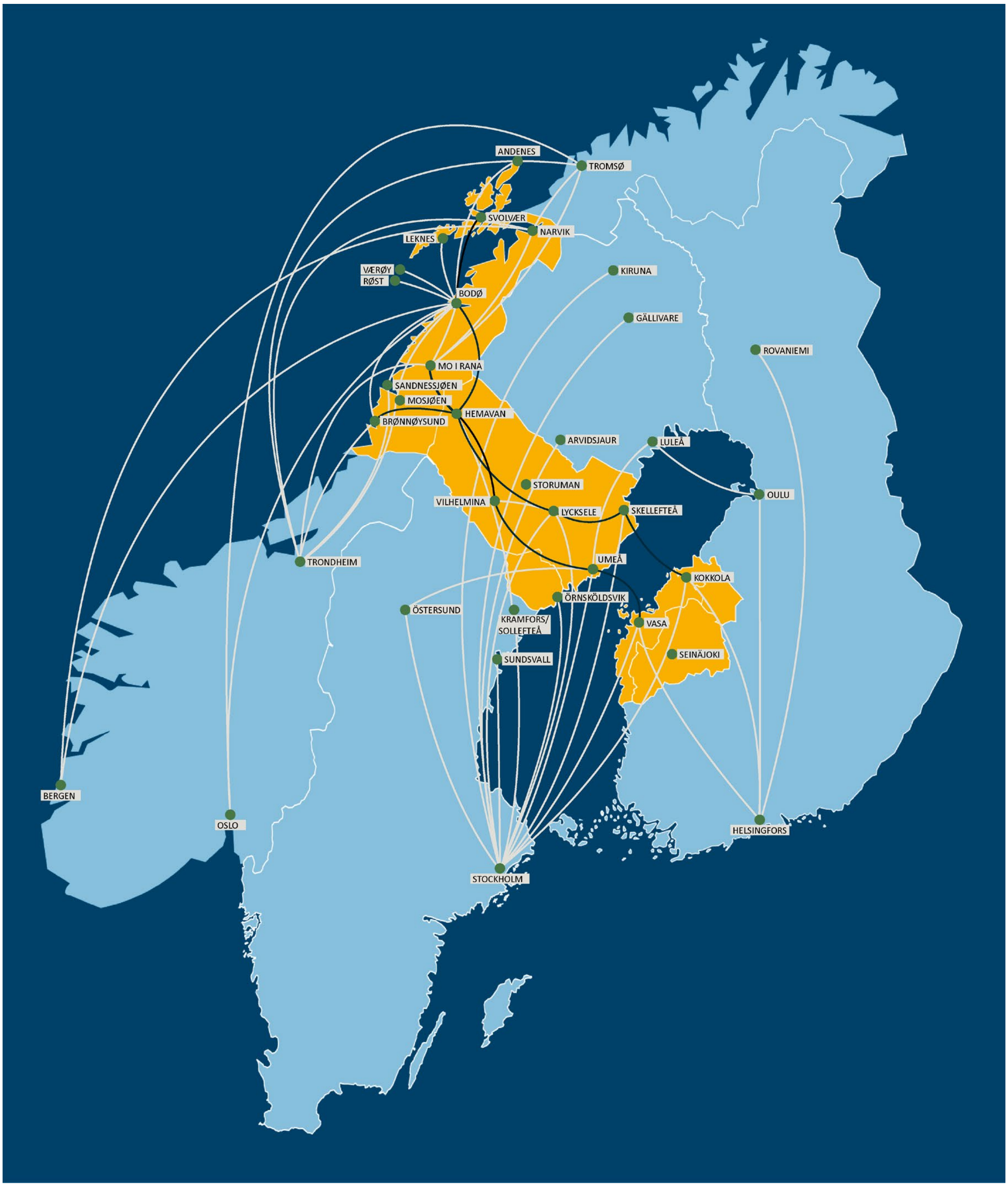
	Start	Stop 1	Stop 2	Stop 3	Stop 4	Stop 5	Stop 6	Stop 7	Stop 8
City	MQN	HMV	LYC	SFT	KOK	SFT	LYC	HMV	MQN
Distance, km	0	70	220	110	150	150	110	220	70
Time of flight, min	0	14	44	22	30	30	22	44	14
Charging effect at airport, kW	1200	700	700	1000	700	1000	700	700	1200
Charging time at tarmac, min	0	6	30	18	60	18	18	24	60
Energy conumption between stops, kWh		141	381	205	269	269	205	381	141
SOC after travel, %		80%	37%	57%	53%	63%	61%	37%	56%
SOC after recharging, kWh		648	617	648	720	648	648	547	720
SOC after recharging %	100%	90%	86%	90%	100%	90%	90%	76%	100%

For the **9-passenger aircraft** (Table 8), the longer range allows stops at Hemavan without charging and then charging for 6 minutes in Lycksele and 12 minutes in Skellefteå before arriving to Kokkola. Using this type of aircraft allows charging within 24 minutes at the airports using a power capacity of 700 kW or more. The 350 kW charger at Hemavan Airport makes stop 7 a bit longer and only increases the SOC by 9% compared with 700 kW charger (18% with the same charging time). This means a 700 kW charger would be a better choice.

Table 8. The required charging power and charging time at the different stops along the flight route Mo i Rana (MQN) – Lycksele (LYC) – Skellefteå (SFT) – Kokkola (KOK) with a 9-passenger aircraft with an 820 kWh battery capacity. SOC = State of Charge.

	Start	Stop 1	Stop 2	Stop 3	Stop 4	Stop 5	Stop 6	Stop 7	Stop 8
City	MQN	HMV	LYC	SFT	KOK	SFT	LYC	HMV	MQN
Distance, km	0	70	220	110	150	150	110	220	70
Time of flight, min	0	10	32	16	22	22	16	32	10
Charging effect at airport, kW	700	350	700	1000	700	1000	700	350	700
Charging time at tarmac, min	0	0	6	12	24	6	0	12	48
Energy conumption between stops, kWh		86	196	115	145	145	115	196	86
SOC after travel, %		89%	66%	51%	70%	82%	76%	52%	50%
SOC after recharging, kWh		734	538	722	820	738	623	496	820
SOC after recharging %	100%	89%	66%	88%	100%	90%	76%	61%	100%

Including these examples in the current map of flight routes demonstrates how flight patterns in this region will begin to include both cross-border and east-west flight routes.



Current routes in Norway, Sweden and Finland with overlay of calculated electrical routes.

4. THE ECONOMY OF ELECTRIC AVIATION

All countries in the region have state-owned airports and employ some sort of cross subsidisation. However, there are substantial differences in the number of state-owned airports in relationship to the total number of airports in each country. Norway has approximately 90% state-owned airports and Finland approximately 85% (where the share of the domestic traffic is even higher). In Sweden, the state owns only about 25% of the airports and has approximately 33% of domestic traffic. This means domestic airports in Norway and Finland have more financial security than in Sweden.[66] However, the Norwegian and Finnish airports are evaluated according to different criteria in order to maintain funding. Sweden's different approach means that more airports in the national network must rely on more external funding, whether local or regional.

The ownership structure of regional airports and government policy significantly impact how regional airports can invest in and build infrastructure for electrified aviation. This creates challenges for policymakers in each country.

It is clear that Norway subsidises routes that are not profitable to a much greater extent than Sweden, but when divided by passenger volumes, the difference mostly vanishes. The reason for this is that Sweden only subsidises routes with very low numbers of passenger.[67]

4.1 BUSINESS MODELS FOR CHARGING

4.1.1 Today

The current business model for supplying fuel at airports involves the fuel company distributing and selling that fuel but the internal airport staff handling the fuel.

4.1.2 Possible new business models for electric aviation

There are different possibilities for the charging business model. Airports own their electrical network and are connected to a local network either as a low-voltage or high-voltage customer and with their own transformer. The airport can distribute and sell their electricity within its area of operation. What is required is charging equipment that converts the mains' alternating current into direct current, which is then connected to the plane using a cable. Airports could sell alternating current to a charging company, which then installs a charger and charges the aircraft operators. Airports could also invest in the charger and charge the aircraft operators. A third alternative is that airports are responsible for all investments but has another company handle the actual billing and sale of electricity to the aircraft operators. Currently, it is common for a fuel supplier to supply the airport with fuel and the airport ensures that the aircraft can be refuelled, while the aircraft operator buys the fuel from a fuel supplier. It is uncertain whether current fuel suppliers are interested in also acting as charging operators. This is an open field for different actors, and there are major uncertainties about the size of the market and willingness to pay.

[66] *Trafikanalys (2019) Flygplatser i fokus. PM 2019:6. p. 41.* https://www.trafa.se/globalassets/pm/2019/pm-2019_6-flygplatser-i-fokus.pdf
[67] *Trafikanalys (2019) Flygplatser i fokus. PM 2019:6. p. 42.* https://www.trafa.se/globalassets/pm/2019/pm-2019_6-flygplatser-i-fokus.pdf

5. DISCUSSION

Development of electrical aircraft is mainly in the 2-19 passenger segment. In a regional perspective, especially in a region including a sea and a lack of railways in some directions, a small electrical airplane might be a convenient way of enabling fast and sustainable travel. It might also be a fast solution for more specific trips, like business trips between big industries or transportation of cargo. The range of aircraft closest to market introduction will be sufficient to cross the Kvarken Strait and reach locations in the inland region. In this relatively sparsely populated region, the number of passengers (2-19) is believed to be rather optimal to fill the planes without having too many travellers.

Routes that might be of interest and commercially viable depend mainly on two types of trips: point to point trips and transfer passengers (primarily from national hubs, such as capitals). This means that new electric flights should be connected to the morning peak (7.00-9.00) and the afternoon peak (16.00-17.00). If tourism can become a driving factor, other times and adjustments may be necessary.

It differs which cities/communities are interesting from a business perspective and which are interesting from an airport's perspective. Factors include other forms of public transportation (primarily train), remote airports (and lack of public transportation), low number of possible travellers and high value tourist locations on the road.

All airports have their own system for arrivals and departures, which means demand differs at each airport. In the same way, each airline has its own flight route for each aircraft. This, together with the timetable, might result in complex and varied demand at each airport. Simulations and estimates are needed to gain a better understanding of demand at a specific airport. For regional travel, when most of the distances are relatively short, it is important to enable a smooth and quick passage through the airport before take-off and after landing. Even though cruising speed for an electric aircraft is lower than a conventional aircraft equipped with a jet engine (around 300 to 400 km/h versus around 800 km/h), the speed will not significantly increase travel times.

At this early stage when no charging standard is in place, the best way for an airport to prepare for electric airplanes is probably to install an airside connection point. This will enable electric aircraft with their own charger to connect and charge. This will allow electric aircraft to use the airport even though no charging standard is in place yet. And the fact is that current electric aircrafts in operation bring their own charger or use the same standard as for cars.

The examples with three routes all show that charging power at the airports needs to be 700 kW or more to enable a turnaround time of 30 minutes. This will of course differ, depending on type of aircraft, battery capacity and type of route or destination. Additionally, more than one aircraft might charge at a time. This adds one more dimension to the calculations. Charging in winter weather conditions will likely take longer than estimates for the routes. Total travel times along the routes are also relatively long, making it difficult to establish attractive timetables. Along with battery development enabling longer range, the optimal choice might be one or two stops on these types of route. However, estimates for market introduction of 9-seater to 19-seater aircraft seem a bit optimistic and apply to the initial certified aircraft.

Financing of charging infrastructure at airports will probably look different in Norway, Sweden and Finland. Ownership of airports looks different in each country, and development of the road charging network currently uses different financing solutions. More information is needed before actual actions for individual airports can be specified and initiated.

6. CONCLUSIONS

This report indicates that the Kvarken-Nordland region will most likely benefit on developing regional electric aviation, with east-west connections. A new option for transport will increase the regions mobility and access, for both businesses and personal travels.

After looking specific into electric aviation and charging infrastructure, the report concludes that:

- *The best way for an airport to prepare for electric aviation at this stage is probably to install an airside connection point. The roadmap on page 17 provides recommended actions for airports to provide charging capacity for electric aviation.*
- *The type of charger (stationary, mobile or battery backup) best suited for a specific airport is difficult to know beforehand. It depends on several factors, such as its size and traffic flows at the airport.*
- *The development of a charging standard is important since this will enable all airports to provide the right connections for charging infrastructure.*
- *Financing solutions for charging infrastructure at airports will probably be different in Norway, Sweden and Finland (due to different owner structures).*
- *The business model for airside charging infrastructure will most likely be airports owning and operating the charging station(s).*

FINDING INNOVATIONS TO ACCELERATE THE IMPLEMENTATION OF ELECTRIC REGIONAL AVIATION

FAIR is to be seen as a first step of preparing the Kvarken region for an early implementation of electric aviation.

The project increases the knowledge base about electric aviation, investigates the possibilities and surveys both the needs and the required technical investments.

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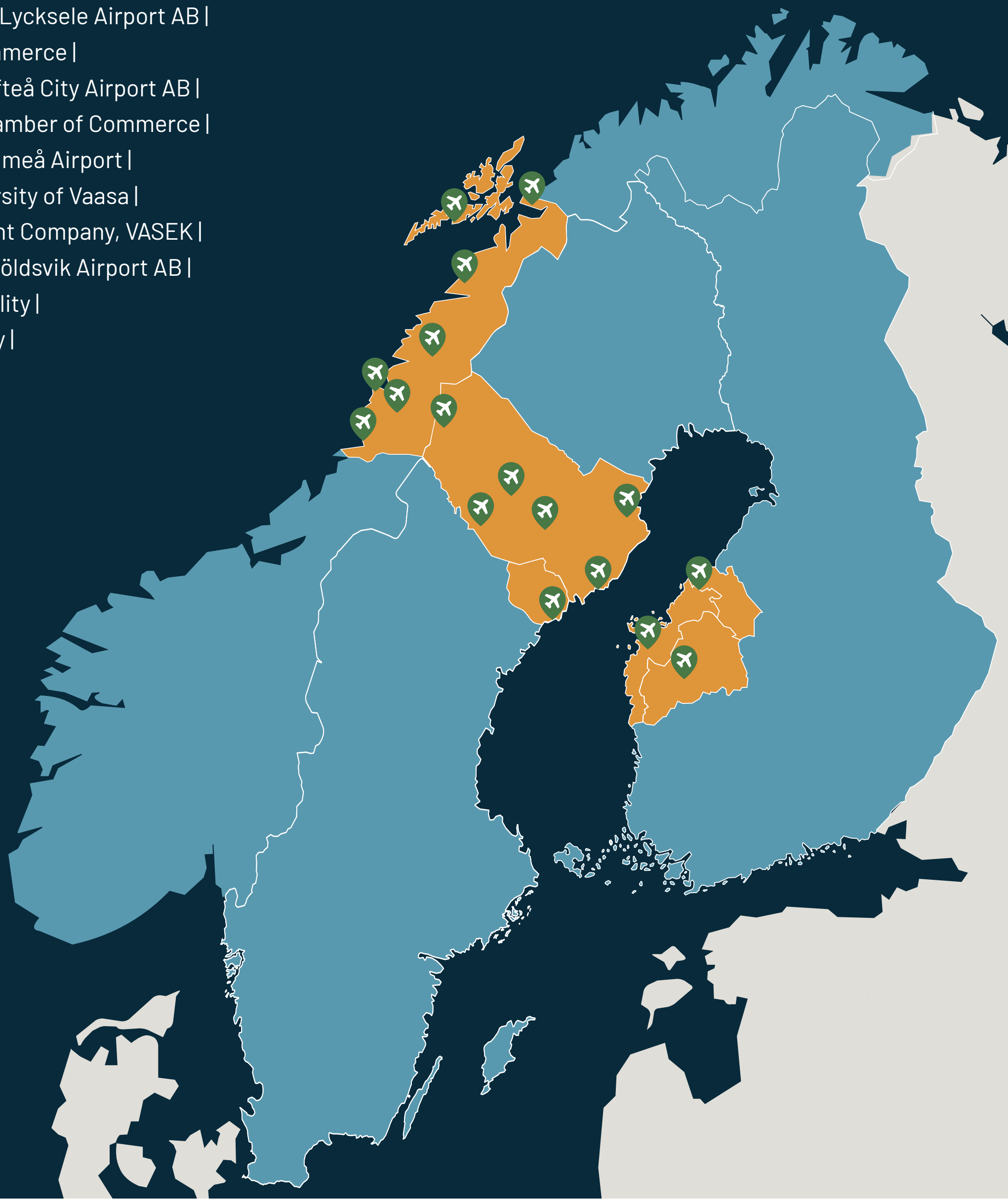

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