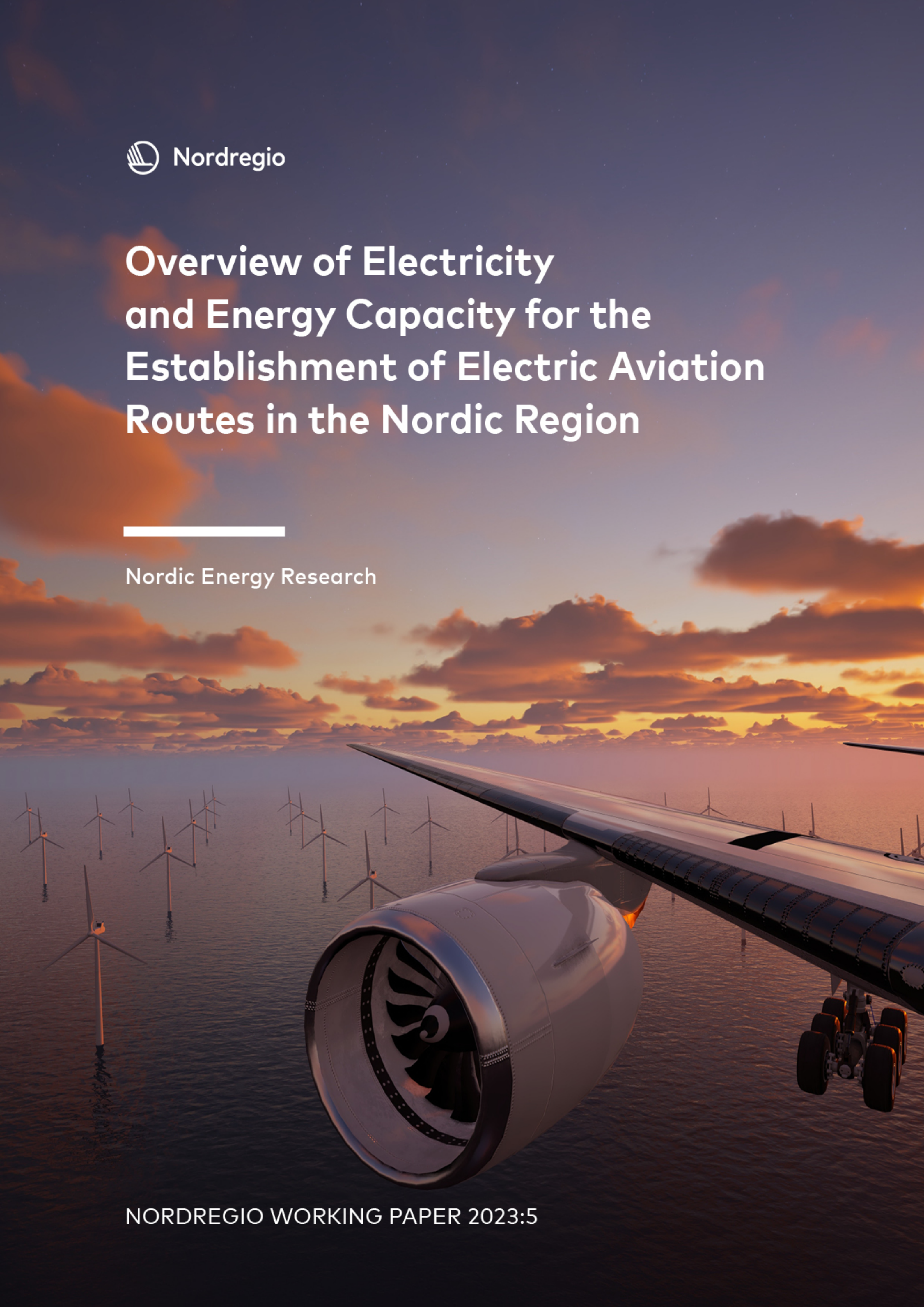
Nordregio

Overview of Electricity and Energy Capacity for the Establishment of Electric Aviation Routes in the Nordic Region

Nordic Energy Research



NORDREGIO WORKING PAPER 2023:5

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Akureyri Airport, Iceland
Photo: iStock

1. Introduction

This report explores which routes in the Nordic Region will be suitable for establishing electric aviation according to two factors: energy demands of airports and regional power adequacy. The report is part of the Nordregio project *Electric aviation and the effects on the Nordic Regions* and substantially builds on the project's *Accessibility study.*

The Accessibility study identified 203 airports in the Nordic Region as feasible for accommodating electric aviation, on the basis of savings in transport time, connecting rural areas with urban or other rural areas, and overcoming cross-water distances or other geographical obstacles. It is impossible to clarify the energy capacity and infrastructure adequacy of all 203 airports within the scope of this report. Consequently, a regional perspective on the power adequacy is applied for the report assessments. This will assist in the selection of reasonable case studies, which will be explored in the next stages of this project, for the first generation of electric aviation in the Nordic Region.

It is important to emphasise that power conditions and connections of local distribution grids differ within regions, as does the energy demand of airports. Standard conditions of battery electric airplanes, power demands, and charging infrastructure are described in the following chapters, with an aim to understand requirements for power capacities and infrastructure to adequately support electric aviation.

Bodø Airport, Norway
Photo: Kent Wang (Wikimedia Commons)

Technical Conditions for Introducing Electric Aviation

Technical conditions and charging options are explored for electric aviation in this chapter. The technical conditions represent standard measures that can differ in practice, e.g., the expected electricity consumption per flight depends on number of passengers and weather conditions. Applied data and information are gathered from reports and articles by Avinor, Electro Flight, Heart Aerospace, and research studies to ensure representative and valid data.

2.1. Battery Specifications of Electric Airplane

The primary focus of this project is on fully electric airplane with a 19-passenger capacity, flying a maximum distance of 200 km for a duration of one hour. These electric airplanes are two-engine models with propellers, corresponding to the EASA CS-23 standard segment (Avinor, 2020) and were the first electric model announced to be launched on the market when the project initiated.

However, it is important to recognise that the first commercial electric airplane is expected now to be a hybrid-electric model due to requirements related to accommodating energy reserves and operational flexibility. The hybrid-electric airplane will allow for more passengers per flight, specifically 30 passengers by 2028, and follows the EASA CS-30 standard segment. Nonetheless, there are examples of EASA CS-23 standardised fully electric airplanes ran as pilot projects in Sweden by Heart Aerospace and in Trondheim by Rolls-Royce. (Avinor, 2020)

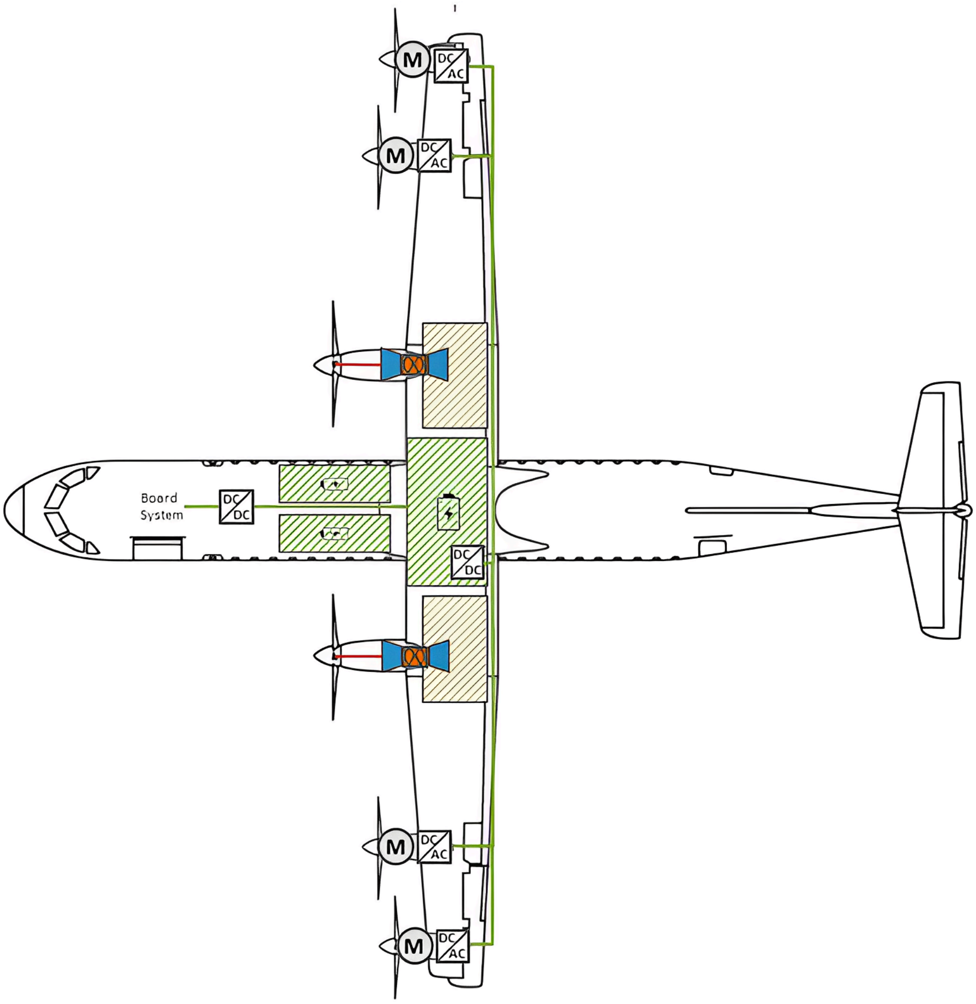

Figure 1: Schematic wingtip propeller architecture for an ATR-72 (hybrid electric airplane). A new arrangement of propulsors can lead to better aerodynamic lift properties of the wing. A variation of this concept is an architecture with two electric-driven wingtip propellers and a conventionally placed gas turbine on each wing (Hoelzen & et.al., 2018).

Standard processes are, additionally, more comprehensive for 30-passenger airplane compared to 19-passenger airplane[1] (Avinor, 2020) Hybrid solutions are generally not considered in this project due to the difficulty in predicting electricity demands that depend on the practical consumption share of electricity and jet fuels per flight.[2]

Batteries function as converters of electric and chemical energy. Today's lithium-ion batteries applied in electric airplane, have a specific energy (energy per mass unit) of around 196 Watthour/kilo (Wh/kg) (Electro Flight, 2022). With technological development, these are expected to provide a specific energy between 400-450 Wh/kg in near future. Solid-state batteries are also in development, which are assessed to have a specific energy of 650 Wh/kg, improving the range and duration of flights. (Avinor, 2020)

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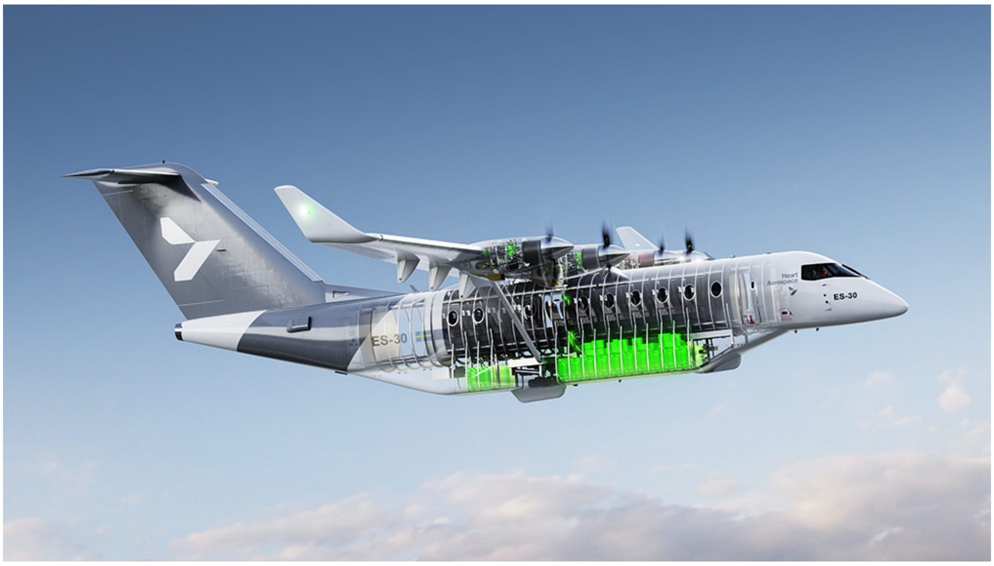
1. The European Union Aviation Safety Agency (EASA) adopts certification specifications for aviation in 31 EU and EØS member states to ensure high security of operations and safety on board. EASA CS-23 targets small to-engine propel airplanes with a passenger capacity of max. 19 and a total weight of 8 600 kg. EASA CS-25 applies to larger, turbine-powered airplanes. (Avinor & Luftfartstilsynet, 2020) Safety requirements are more comprehensive for CS-25 airplanes due to the larger size, weight, the centre of gravity, airspeed, and power (European Union Safety Agency, 2021).
2. Yet, hybrid solutions might be taken into consideration in individual case studies of this project, depending on specific plans of the selected airports to introduce hybrid solutions in the nearer future.

The specific energy of batteries is important due to the weight of them, which limits the size that can be feasibly installed in airplanes. Consequently, the battery package of a fully electric 19-passenger and a hybrid-electric 30-passenger airplane is the same. Routes designated in the Accessibility study are, therefore, applicable to hybrid-electric airplane as well, in case they only operate on electricity.

Heart Aerospace has announced that their first hybrid-electric airplane will carry 30 passengers, hence, technical specifications of the battery package can be applied for this project (Heart Aerospace, 2023). The installed SEED battery package, produced by Electroflight, will weigh 5,000 tons (Electro Flight, 2022), which makes it possible to overcome 200 km. on electricity (Heart Aerospace, 2023). As a result, the airplane battery package will contain an energy capacity of approximately 980 kWh[3], roughly equalling the battery capacity of 10 Tesla Model S (Long Range). A battery is most efficient when charged to around 80 % – 90 % of its capacity, which equals to around 780 – 880 kWh. Besides achieving higher efficiency, the battery lifetime is extended.

A CS-23 electric airplane theoretically consumes 570 kWh[4] electricity to cover a 200 km distance with 19 passengers on board, which is calculated based on an expected energy consumption of 0,1 – 0,15 kWh per seat km (Reimers, 2018). This consumption equals 58 % of the total energy capacity, but it will vary in practice due to, e.g., weather conditions and luggage weight. The battery must also not be charged to less than 5-10 % of its capacity, as a safety measure and to maintain the battery lifetime.

Duration of flights for the CS-30 hybrid-electric airplane is indicated to be 200 km on electricity, 400 km on electricity and hybrid, and 800 km on electricity and hybrid with 25 passengers, with a battery charging time of 30 minutes (Heart Aerospace, 2023). While the 200 km flight distance can be extended in practice, this is not considered in *the Accessibility study* due to data limitations. However, potential routes not exceeding 250 km are assessed for the designation of routes as Nordic case studies.



Picture 1: Image of Heart Aerospace Electric Airplane (Heart Aerospace, "Heart ES-30 Battery System", 2023).

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[3] Calculation: (196 Wh/kg x 5 000 kg) /1 000 = 980 kWh.
[4] Calculation: 0,15 kWh * 19 passengers * 200 km = 570 kWh.

2.2. Charging Infrastructure and Power Requirements

Electrification of airports requires an increased power supply to meet the electricity demands of electric aviation. As the introduction of electric aviation is still in an early phase, the prerequisites for charging infrastructure and power requirements of airports are uncertain and not yet measured (Avinor & Luftfartstilsynet, 2020). Therefore, general considerations regarding power requirements and charging infrastructure of airports in connection with electric aviation are discussed in this section.

2.2.1. Power Requirements of Grid Connection

Avinor has compiled a study on power capacity demands of small airports that introduce electric aviation, and in general undergo an electrification of their land-based operations and services. It is anticipated that the total charging demand of small airports will span between 1-10 MW in the case of implementing fast charging. (Avinor & Luftfartstilsynet, 2020)

Additionally, Heart Aerospace recommends installing 1 megawatt (MW) charging power per airplane to fulfil turnaround time demands. Turnaround time is the time required to charge an airplane before its next flight (Heart Aerospace, 2023), which the study estimated at 30 minutes.

1 MW charging capacity requires at least a 1 MW transformer connection between the airport and the power grid to transform alternating current power from the grid to direct current power that can be stored in a battery. In a 2022 study by the Austrian Institute of Technology, multi-megawatt fast charging options are investigated for heavy-duty vehicles. One of the conclusions of the study is that low voltage grids will be negatively affected by coupling multi-megawatt charging equipment (< 1 MW) to them, due to risks of causing high currents and thereby disrupting power grid stability. Instead, they must be connected to at least 1 kilo volt (kV) distribution grids, depending on the charging capacity requirement. (Makoschitz, 2022) These are classified as high voltage distribution grids in Norway (Olie- og energidepartementet, 2019) and in EU terms as medium-voltage grids (European Commission, 2018) and are typically managed by DSOs.

2.2.2. Charging System Options

An airport must be connected to at least a 1 kV grid in case of plug-in charging of electric airplanes, to avoid causing disturbances/high currents on the local and national power grid. However, there are charging alternatives that can accommodate electric airplane at airports that are not geographically close to a power grid, with sufficient voltage to become economically or technically feasible for connection.

There are three charging options:

- *Direct charging from the power grid (plug-in):* Charging equipment is connected directly to the local power grid, which the airplane can connect to by an electrical cord. Electricity from the grid is provided on-demand.
- *Stationary batteries:* Large-scale batteries are installed at the airport to store electricity from the grid or from local power production units, such as onshore wind turbines or photovoltaics. Charging equipment is connected to the

batteries and the local power grid.

- *Swappable batteries:* A battery station is installed at the airport, containing swappable batteries that can replace discharged batteries from airplane. The charging option is only suitable for electric airplane with a displaceable battery package. (Avinor & Luftfartstilsynet, 2020)

With increased share of fluctuating renewable energy in Nordic power grids, especially in countries relying on wind and solar power, batteries become important for airports accommodating electric airplanes. By investing in stationary or swappable batteries, airports can adjust their consumption to periods with high renewable electricity production that both support the sustainable transition of energy systems and increase security of supply. The charging solutions also entail cost savings because electricity prices are generally lower during periods with a high share of renewable energy in the grid, due to the Nordic spot market price regulation in Denmark, Sweden, Norway, and Finland (Nordic Energy Research, 2023).

Iceland has no cross-border transmission lines; hence it has a closed national market structure. Electricity prices are determined based on average prices of the respective utility company, with respect to customers consuming more than 100 giga watthour (GWh) electricity per year. Tariffs can be higher for rural areas due to higher distribution costs compared to urban areas. (Electricity Act, NO. 65/2003, 2022)

Besides having a positive effect on airports, battery storage can provide flexibility to the national power supply, because airports can smartly charge according to electricity peak production periods. As such, the need to improve national grid capacity decreases. This charging concept is defined as smart charging and is applicable to other vehicle types, such as electric cars. For the three options, stationary and swappable batteries can provide smart charging, and are therefore considered the best charging solutions to ensure high security of supply and stability to the national power grid.

On the other hand, smart charging demands logistical planning of airports to ensure batteries contain enough power for charging airplane in accordance with scheduled departures. Furthermore, grid connection in many cases is a prerequisite because of risks related to establishing local microgrids transferring locally produced energy, e.g., from wind turbines and photovoltaics due to limited reserves or regulation options for situations with low or high frequencies.

Stavanger Airport Sola, in Norway, is an example of an airport that has initiated the process of implementing power and charging infrastructure to accommodate electric airplane. Under the demonstration programme, Elnett21, five partners, including Avinor, have engaged in developing a smart, local power system in Sola Municipality, to enable increased electrification of transport activities in the area. Some of the initiatives include the implementation of large-scale stationary batteries, local photovoltaics and wind turbines, as well as smart-meter control systems to support smart charging. On the Elnett21 webpage, more information can be found about the programme as inspiration for the case studies.[5]

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5. Please find the link to the Elnett21 website: https://www.elnett21.no/

Picture 2: Heart Aerospace ES-19, Heart livery (Heart Aerospace, "Heart Aerospace ES-19, Heart livery 2", 2023).

Kajaani Airport, Finland
Photo: Finavia

3. Power Grid Capacity and Infrastructure in the Nordics

Electrification of energy systems can be a cost-effective enabler for transitioning the energy, industry, and transport sectors (Nordic Energy Research, 2021). Electrification requires increased capacity and management of power grids to tackle high power demands and fluctuating energy production because of a high share of renewable energy sources. Consequently, the future demand and supply of energy cannot be balanced without taking adequate measures to ensure high energy security. For instance, by implementing energy storage solutions and smart energy consumption measures.

Introducing electric aviation implies that airports will undergo an electrification process that will increase their electricity demand. This requires sufficient connection to the local grid, to meet future demands and ensure backup supply in case of shut down of power units or insufficient weather conditions for e.g., wind and photovoltaic power production. In the Nordic countries, some regions are more favourable for airport electrification than others, as these regions experience a surplus of electricity production and stability of transmission and distribution grids. These regions are outlined in the following chapter to add perspectives to the selection of case studies, to be analysed in the next stages of the project.

3.1. The Nordic Power Grids and Adequacy

The electricity systems in Denmark, Sweden, Finland, and Norway are highly interconnected through cross-border transmission lines and the Nordic spot market structure (Nordic Energy Research, 2023). This is illustrated by the Swedish Transmission System Operator (TSO), Kraftnät, in Map 1. The transmission lines indicate regions where largest amounts of electricity are transferred, enabling airports to become increasingly supplied by renewable energy. Distribution grids are not depicted on the map, hence, Map 1 only provides an overview of the main electricity transfers. Distribution grids hold a capacity of less than 220 kV and are principally managed by DSOs, whereas transmission grids are managed by TSOs. Therefore, national TSOs and DSOs can assist in clarifying whether local grid conditions are adequate for supplying specific airports which plan to become electrified.

The electricity system of Iceland does not have any interconnections, due to its geographical distance from other countries. The transmission grids in Iceland are visualised in Map 5.

Regarding stability of current grids, Nordic Energy Research recently published a study "The Nordic Energy Trilemma" (norden.org). The report identifies high-risk factors f0r the Nordic energy transition, in terms of energy security and potential socioeconomic consequences. One of the most salient energy security risks is inadequate investment and construction of power infrastructure and grid connections. With increased electrification, there will be new supply and demand patterns, which place greater requirements on smartly operated power systems to meet future demand. This risk can be mitigated by adding interconnectors between countries and developing storage options such as batteries. Investment in improved power grids is assessed to be inadequate, which in turn disincentivises development of renewable energy technologies, e.g., due to low grid connectivity, risk of congestion, or high tariffs. (Nordic Energy Research, 2023)

Consequently, in the first phase of introducing electric airplane, it is favourable to focus on airports in regions where electricity adequacy is currently assessed to be sufficient. Here follows an overview of the Nordic countries’ national energy and infrastructure capacity adequacy, in relation to airports with interesting route connections.

Map 1: The Nordic countries' transmission grids, including Denmark, Sweden, Finland, and Norway. The map is produced by Svenska Kraftnät. (Svenska Kraftnät, 2021).

3.1.1. Denmark

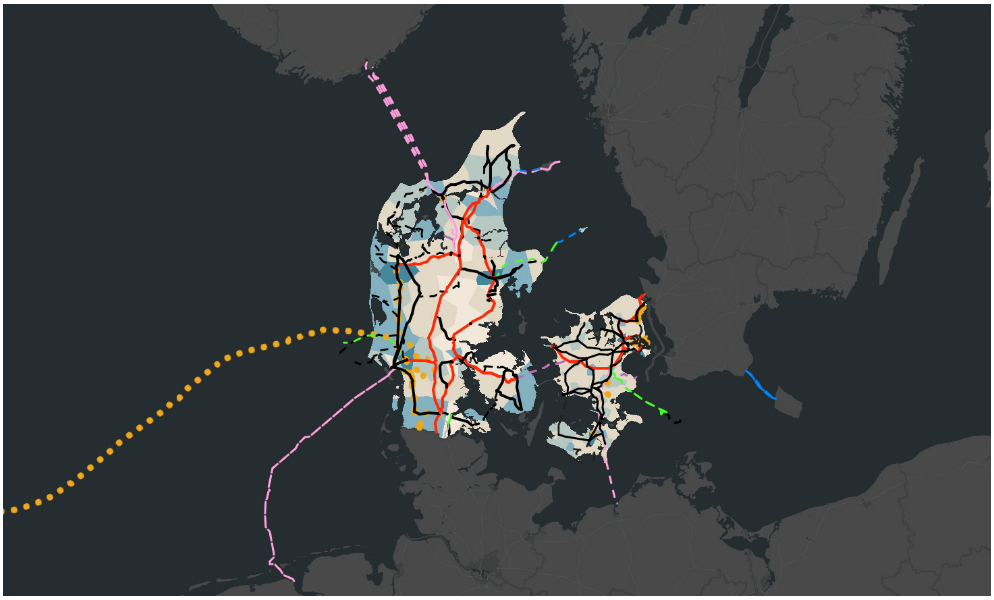
Characteristically for Denmark, electricity is transferred from the electricity market bidding zone DK1 (Jylland and Fyn) to the bidding zone DK2 (Sjælland), because of surplus production of electricity in DK1 and an experienced deficit in electricity production for DK2. Additionally, there is a high consumer density and level in DK2 compared with DK1. As a result, electricity production and grids must be strengthened, particularly in DK1, to sufficiently supply airports with electricity.

The Danish TSO, Energinet, in cooperation with the Danish interest organisation Green Power Denmark, has conducted a power capacity mapping exercise investigating, e.g., the power coverage rate of Danish municipalities. Some municipalities experience surplus power production, which indicates a potential for new electricity consumers to enter or current consumers to increase their consumption, such as airports. The map shown in Map 2 is particularly useful for this project.

According to Map 2, it can be assessed that Aalborg airport is reasonable to investigate as a case study, because Aalborg municipality has a consumption rate at around 210 %. It indicates that the electricity production in the municipality is above twice as high as the consumption. Furthermore, Aalborg airport offers both domestic and international flights, and can accommodate beneficial cross-water connections to Norway and Sweden according to *the Accessibility study.*

Another airport identified with beneficial time connection potentials is Karup airport, in the central part of Jutland. Karup airport is in Viborg Kommune, which has a low power coverage rate (around 18 %). This raises uncertainty as to whether Karup airport can sufficiently be supplied with electricity for electric airplane. Local power production and storage solutions must be considered, to accommodate electric airplanes during the first phase introduction of electric airplane. On the other hand, with Western Jutland being one of the least urbanised areas of Denmark, and with neighbouring municipalities to the west experiencing high power coverage rates, the rationale for selecting Karup airport as a case study is reasonable due to its potential to offer favourable time benefits, e.g., compared to Copenhagen.

Measures on the power coverage rate of Bornholm regional municipality are not clarified in the mapping exercise by Energinet and Green Power Denmark. However, national plans to build an energy island on Bornholm makes its Rønne airport relevant for investigating the potential for electric aviation as a case study, also considering it is classified as a rural airport with open water connections only. In total, an in-creased offshore wind capacity of around 3 GW is expected to be installed in 2030 (Bornholms Regionskommune & et. al., 2023). Additionally, the results of the case study can be applicable for Åland, where construction of 6 GW of wind power capacity is planned, to make Åland an energy hub and a smart energy island. Therefore, selecting Rønne airport can add relevant perspectives for both cases (Pyrhönen & et.al., 2021) However, the time perspective of introducing increased wind power capacity must be considered for the case study.



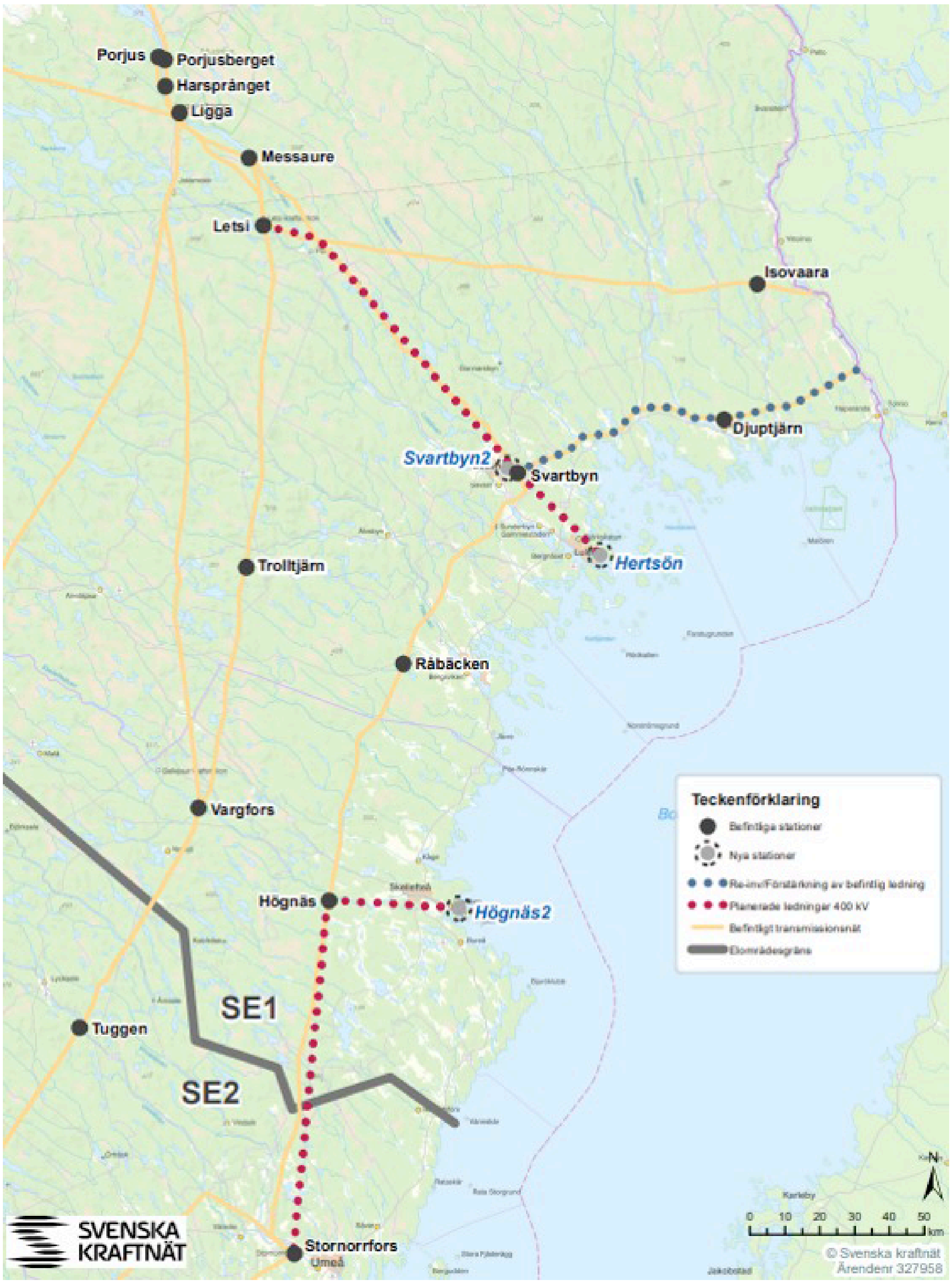
Map 2: The power coverage rate of Danish municipalities. Blue colours indicate a surplus production and beige colours a deficit consumption of electricity. (Energinet & Green Power Denmark, 2021).

3.1.2. Sweden

The situation in Sweden is similar to that of Denmark. The stability and consumption coverage rate of the Northern Sweden is generally higher than Southern Sweden, which has resulted in congestion and bottlenecks between the two regions. (Svenska Kraftnät, 2015) Consequently, it is beneficial to investigate the potential of electric aviation in the Northern part of Sweden, which is largely rural according to *the Accessibility study.*

Several small airports can be selected in the Northern part of Sweden. A relevant argument for choosing specific airports is geographical proximity to projects under the *"Fossilfritt övre Norrland"* (FÖN) investment programme, implemented by Svenska Kraftnät. The FÖN programme focuses on developing power grids to electrify industries in Northern Sweden (Svenska Kraftnät, 2022) For example, Umeå and Skellefteå airports are located close to one of the transmission projects, extending the transmission grid of 400 kV from Högnäs to Stornorrfors and from Högnäs to Högnäs 2 respectively (see Map 3). The aim is to introduce more power from wind turbines to the grid and supply heavy industry consumers. Regarding the Accessibility study, Umeå and Skellefteå are two of the airports that can enable cross-border connections to Finland. For example, Vaasa and Ylivieska airport.

Regarding Norrbotten, the Northernmost part of Sweden, Kiruna airport can provide time benefits between Norway (Narvik and potentially Bodø) and Finland (Kittilä and Enontekiö). Kiruna airport is not close to any projects under the FÖN programme, but Norrbotten is a net supplier of electricity, hence it is considered relevant for inclusion as a case study. Furthermore, Svenska Kraftnät collaborates with companies, industries, universities, authorities, and interest organisations under the AGON project, which investigates initiatives to achieve a sustainable energy transition of the Norbotten region, e.g., electrification investment opportunities and fuel alternatives for aviation. (Luleå Business Region, 2023) This project signifies interest from national and local stakeholders to engage in innovative projects that increase the feasibility of introducing, e.g., electric airplane in Kiruna airport.



Map 3: Initiated transmission grid projects under the FÖN programme (Svenska Kraftnät, 2022).

3.1.3. Norway

In Norway, the power system has stabilised across the country following the energy crisis in 2022, which resulted in bottleneck issues between Northern to Southern Norway. For years, the Nordland, Troms, and Finnmark regions have been net suppliers of electricity to Southern Norway, Sweden, and Finland, due to low consumption rates owing to sparse population density and large hydropower potential.

In Nordland, Troms and Finnmark, the national grid has the potential to increase the power supply by a total of 2 200 MW in an ordinary year. In dry years, the hydro power reservoirs cannot provide similar amounts of electricity, which must be accounted for. Therefore, new power production, e.g., from offshore wind and hydropower plants, is a prerequisite along with grid expansion (Statnett, Områdeplan Nordland - Forventer stor industrialisering i Nordland, 2023)

However, plans by Statnett highlight potential energy security risks, particularly in Nordland where several industries aim to become electrified. The national TSO outlines that power demand could increase by 400 % in Nordland based on recent electrification plans. Currently, the grid can accommodate a 50 % increase in power demand, equal to 650 MW. It is therefore of high importance that industries and large consumers, such as airports, consider flexible demand and smart consumption solutions, to support grid stability according to variable electricity production from renewables. These risks can be mitigated by improved grid capacity and connections in the region. (Statnett, Områdeplan Nordland – Forventer stor industrialisering i Nordland, 2023)

Current projects are relevant for airports in Mo i Rana, Mosjøen and Narvik. These three rural airports could be candidates for a case study in Norway, with connection to Bodø as a regional transport hub and urban junction. Additionally, Bodø and Narvik airport have route connection potentials to Kiruna airport in Sweden, enabling synergy between Swedish and Norwegian case studies. Tromsø airport can also be reached from Narvik airport. Many large industries are in Mo i Rana is, hence, Statnett emphasises a need for conducting comprehensive modernisation and improvements of the local power grid to meet future demand. Synergies between these projects, and an electrification of Mo i Rana airport, should therefore be considered. (Statnett, Grid Development Plan 2021 – Summary, 2021)

The power grid in Vestlandet will be strengthened in coming years, particularly in the Bergen region. Stavanger airport is also engaged in a project to develop grid connections, by constructing a local microgrid to supply electricity to both Sola airport and the Port of Stavanger (Elnett21, 2023). However, these two facilities are in relatively urbanised areas of Norway. Airports north of Trondheim are of greater interest to include as a case study, due to their potential to improve connectivity in rural areas of Norway.

Picture 3: Stavanger Airport in Norway (Flickr Commons).

3.1.4. Finland

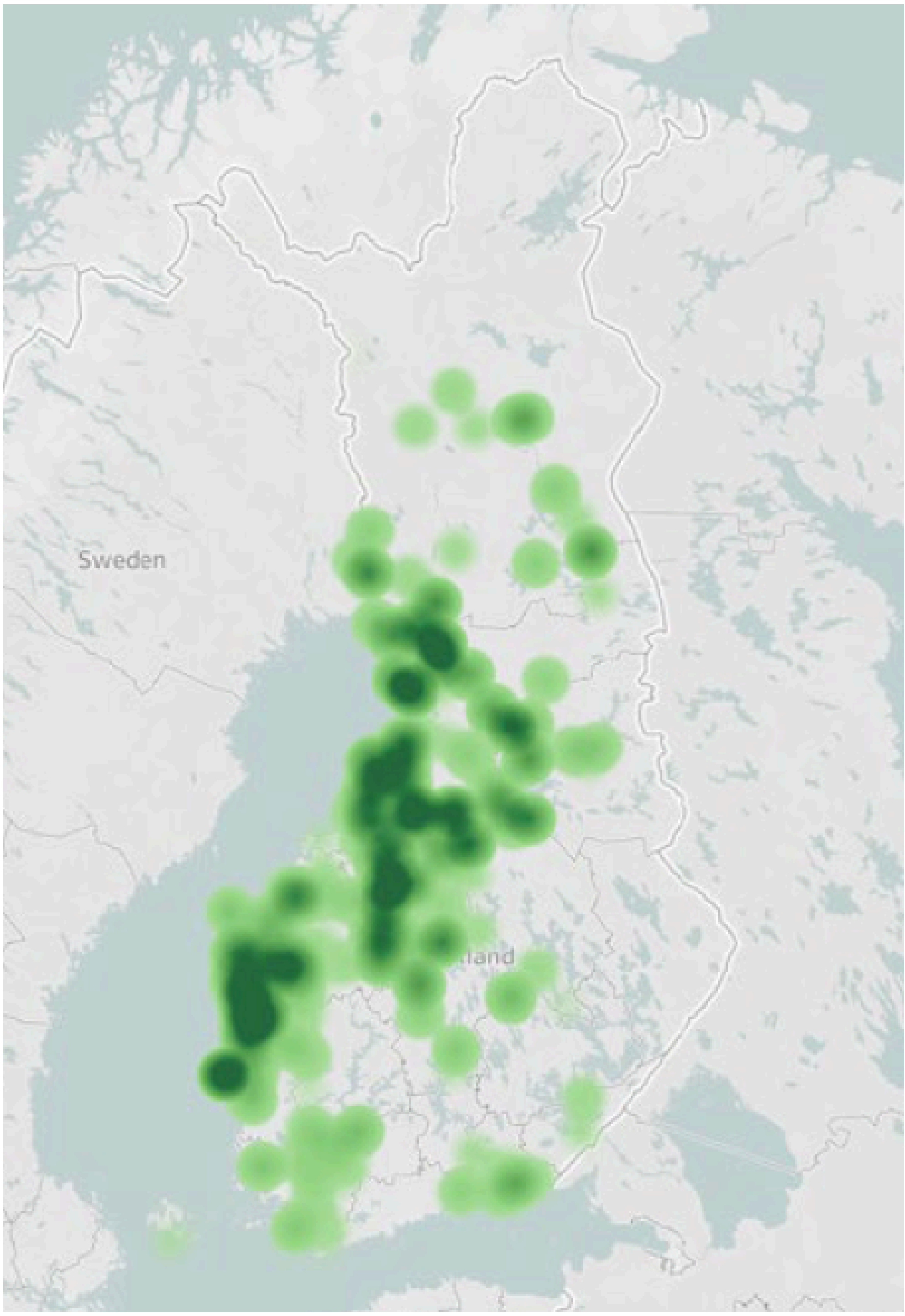
Fingrid is the national TSO that operates Finland's transmission grid and cross-border connections. In a 10-year plan for 2022 – 2031, Fingrid defines the power grid and capacity situation of each region with a description of current grid development plans (Fingrid, n.d.). The 10-year plan is considered here, to assess power grid adequacy for electric airplane in Finland.

Characteristically for Finland, the country has a strong main grid, and regional bottlenecks are not experienced to the same degree as in Norway, Denmark, and Sweden. However, there is surplus power production in Northern Finland, including the Lappland, Norra Österbotten, and Kajanaland regions, and a deficit in Southern Finland, primarily in the Nyland region, where Helsinki is located. (Fingrid, n.d.)

In the Lapland and the Sea-Lapland area, the power grid can supply new or existing electricity consumers with more electricity, which provides the potential for the Rovaniemi, Kittiliä and Enontekiö airports to introduce electric aviation (Fingrid, n.d.). Vaasa, Kauhava and Kauhajoki airports are also highlighted as having time beneficial connections to Sweden, according to the "Accessibility study". These are places in the Ostrobothnia area that, with new grid constructions, can supply new consumers with electricity. Furthermore, the area has a high share of wind power production, with further projects in development, which implies a reasonable potential for electric aviation in the region. (Fingrid, n.d.)

Two airports placed in East Finland, Kajaani and Kuusamo airport, are not designated in *"the Accessibility study"* due to no measured time savings by flight compared with on-land transport or distances above 200 km to other airports. However, they are in rural areas of Finland and as indicated on Map 4 located in inland areas with wind power production. Hydropower is mentioned in addition. (Fingrid, n.d.) Therefore, it could be interesting to discover potential route connections to these two airports in the Finnish case study to increase the mobility between the country's rural areas in a large network.

Regarding Southwest Finland, the transmission grids must be reinforced to supply new consumers in the region. This creates uncertainty related to the introduction of electric aviation in Turku airport, which has the potential to be a regional transport junction to Åland. (Fingrid, n.d.)



Map 4: Locations of public wind power projects in Finland. (Fingrid, n.d.).

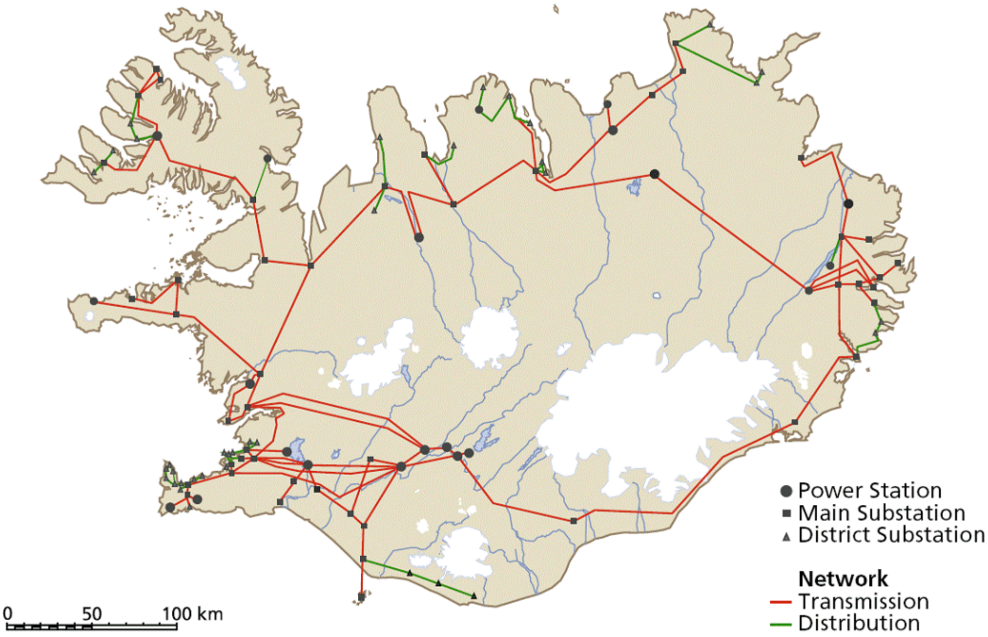
3.1.5. Iceland

The Icelandic power grid is modern and one of the world's most reliable, implying high energy security. Landsnet is the national TSO that operates transmission grids with a capacity of 33kV and 220kV. (Government of Iceland, 2023) As such, the task of choosing case studies is similar to that of Finland, where national bottleneck issues are not as significant. Map 5 shows the national transmission and distribution grids managed by Landsnet.

In *the Accessibility study*, Akureyri airport is designated as a potential junction for aviation. The energy adequacy in the area is high, which supports this designation from an energy perspective. However, an important consideration is the infrastructure adequacy in the Northwest part of Iceland, specifically Thorshofn and Bakkafjordur airport, where grid connections are limited. Akureyri airport can primarily accommodate rural connections to an urban area for this part of Iceland, but potentially also to Reykjavik.

Looking to another rural area, Bíldudalur airport could be an interesting candidate to investigate further potential for electric aviation. The airport has good grid connection potential, and a back-up unit is installed with a 10 MW capacity, which is adequate to supply a small airport with high-power demand. However, considering the number of inhabitants in the upland area and road connections, it is uncertain whether investment in electric airplane infrastructure is feasible. Investigating a potential aviation junction for the greater upland area in Akureyri may therefore be of greater interest, to increase connectivity between the two largest cities in Iceland.

There exist other strategies to achieve carbon-neutral or low-carbon aviation than battery electric ones. These solutions are elaborated on in the next chapter to add a perspective on the development of jet fuels.



Map 5: Map of the national Icelandic transmission and distribution grids managed and operated by Landsnet. (Orkustofnun, 2023).

Svalbard Airport, Norway
Photo: Håkon Daae Brensholm (Visit Svalbard)

4. Development of Alternative Fuels for Aviation

Technological development in the aviation space is moving fast. Time estimates regarding the introduction of alternative carbon-neutral or low-carbon solutions to substitute fossil-fuels for aviation are compiled, to outline future technical options.

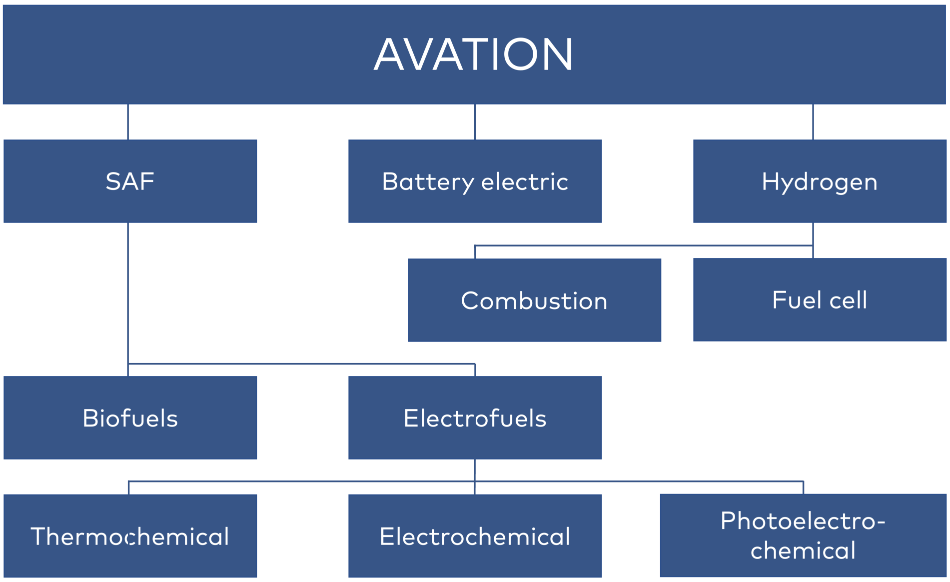


Figure 2: Strategies for decarbonising or to reduce carbon-emissions related to aviation (Douglas & James, 2022)

Figure 2 is created by the Worldfund and indicates carbon-neutral or low-carbon strategies for aviation. The figure suggests that hydrogen and sustainable aviation fuels (SAF) are competitive solutions to battery electric propulsion systems. (Douglas & James, 2022)

Hydrogen is not yet applied for aviation due to several limiting factors, including high costs, sparse supply chains, technological immaturity, and lack of certification specifications. Hydrogen-powered airplanes are firstly expected to be operational by 2040, according to the Worldfund. (Douglas & James, 2022) However, according to a Nordic study compiled by Niras, Syddansk University, and Nordic Initiative for Sustainable Aviation (NISA), the first hydrogen airplane is expected to be introduced between 2027-2030 in the Nordic Region (Mortensen & et.al., 2019). Generally, there is uncertainty related to the pace of developing hydrogen propulsion systems for aviation.

Biofuels, on the other hand, are increasingly utilised as a blend-in-fuel, substituting a share of fossil-fuels in jet fuels. Due to compatibility with existing fossil-fuel based propulsion systems, lower carbon content, as well as immaturity and uncertainty associated with other alternative strategies, biofuels are expected to play a significant role in reaching 2030 and 2050 carbon reduction targets. However, the energy density of biofuels is lower than fossil fuels, and regional feedstocks of biomass are considered inadequate to meet future demands for Nordic airborne transport, hence, other solutions must be accounted for. (Mortensen & et.al., 2019)

Electro-fuel is a term for fuels synthesised from renewable electricity, hydrogen and a carbon source or nitrogen that can be used as drop-in fuel for, e.g., airplanes. Electro-fuels share similar limitations as hydrogen; hence, the fuels are not applied for aviation yet. The production of hydrogen and electro-fuels requires a large scale-up of electricity production to meet future demand, because of an energy system efficiency factor of around 50 %. Consequently, around twice as much electricity is required to fulfil aviation demands by electro-fuels compared with electricity. (Hansson & et.al., 2016). Direct usage of electricity is therefore preferable, considering the uptake of land and material resources to enable hydrogen and electro-fuel production.

It should be noted that hydrogen, biofuels, and electro-fuels are primarily considered in relation to long-distance flights, due to the higher energy density and avoidance of including a heavy battery package in the airplane. Therefore, small battery electric airplanes are not expected to meet competition from these alternatives, except from biofuels which are currently available as a blend-in-fuel to reduce carbon emissions.

Photo: iStock

5. Conclusion

Specific Nordic routes are recommended for selection as case studies based on the regional power grid capacity. In general, all Nordic countries consider electrification as a key enabler for decarbonising the energy and transport sector. However, increased power production and consumption necessitate improvements and extension of current power grid, to meet future energy demand and avoid congestion. Additionally, power consumers need to apply smart consumption measures, to assist in stabilising national power grids, where fluctuating renewable energy production will constitute a high share.

In Denmark, Aalborg airport currently has a strong foundation for establishing electric aviation, based on the power grid in the municipality. However, Karup and Rønne airport can connect rural areas with urban areas, such as Copenhagen. While the power capacity situation in Karup is uncertain in terms of adequacy for supplying electric aviation, the benefits of introducing electric aviation are interesting to investigate, since the airport currently offers only a few domestic connections.

Umeå, Skellefteå, and Kiruna airports in Sweden are interesting to investigate as case studies. Umeå and Skellefteå airports can serve routes to Finland, and Kiruna to both Finland and Norway. All three airports are in the Northern part of Sweden, where the power adequacy is high, and several projects focusing on electrification of heavy industries and transport are underway.

In Norway, Bodø is an interesting case study to investigate as a local junction for electric aviation with connections to, e.g., Mo i Rana, Mosjøen and Narvik airports, which are all located close to planned power grid projects operated by Statnett. Additionally, Narvik and Bodø airports have the potential to accommodate routes to Kiruna airport in Sweden.

Regarding Finland, there are several options due to high power grid adequacy in the country. However, airports placed in Lapland and Sea-Lapland, including Rovaniemi, Kittiliä, and Enontekio, as well as airports in the Ostrobothnia region, including Vaasa, Kauhava and Kauhajoki airports, are relevant to consider as case studies due to high power coverage rates. Kauhava, Vaasa, and Kauhajoki airports can provide cross-water connections to, e.g., Umeå airport in Sweden. Inland airports such as Kajaani and Kuusamo airport can also be considered to increase the connection of rural areas domestically.

In Iceland, energy adequacy and grid connections are strong throughout most of the country, hence, energy supply is not a concern. However, limitations regarding population density should be considered in some areas, where the demand for aviation might be too low for electric aviation to be feasible. Therefore, Akureyri airport, which has a solid national power grid is interesting to investigate as a local junction for electric aviation, with connection to, e.g., Reykjavik.

It is important to keep in mind that the choice of charging system can increase the feasibility of establishing electric aviation by, e.g., installing battery systems that enable charging, when renewable power production is high. This provides stability for the national grid, as well as low energy prices, and possibilities for smart consumption. However, the initial investment cost of batteries may be a barrier for the feasibility of introducing electric aviation.

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Klaus Skytte, Marton Leander Vølstad, Ditte Stougaard Stiler

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Nordregio
Holmamiralens Väg 10
Skeppsholmen
Stockholm, Sweden
www.nordregio.org

Nordregio

P.O. Box 1658
SE-111 86 Stockholm, Sweden
nordregio@nordregio.org
www.nordregio.org
www.norden.org