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Airports with increased electrification – an ongoing project with case studies in Sweden

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Summary

Electrification of the transportation sector will likely increase in the coming years, and there is a focus on limiting emissions from aviation. In Sweden, the goal is to have domestic flights free from fossil fuels 2030. Within the project "Resource-efficient energy system solutions for airports with a high share of electric aviation", increased electrification at airports is studied, with charging future electrified aircrafts, ground handling vehicles, batteries, and local renewable electricity generation. The aim of this paper is to present preliminary initial results from the ongoing project, including models and case studies for Skellefteå Airport and Visby Airport in Sweden.

Keywords: charging, electric drive, electricity, infrastructure, energy consumption

1 Introduction

Electrified aviation has gained more interest among policymakers, aviation stakeholders and the public. The current dominant design in aviation is fossil fuel powered aircrafts. It is estimated that aviation accounts for approximately 3% of the global CO2 emissions [1], while some argue that it may have a higher impact on the climate [2]. Due to the Covid-19 pandemic, decreased flying could be a temporary societal change [3]. To limit emissions from the aviation sector, fully electrified aircrafts with zero tailpipe emissions are of interest. A higher penetration rate of electric aviation likely requires continuous improvements in battery technology (i.e., higher energy density, reduced costs, and lower weight) and a modified airport infrastructure to host electrified aircrafts. In addition, airports can be designed to enable increased electrification in auxiliary services and charging of other vehicles, such as buses, taxis, ground handling vehicles etc. The electricity demand at airports will likely increase in the coming years, along with investments in new charging infrastructure, local power generation and energy storage. This paper presents initial results from an ongoing research project: "Resource-efficient energy system solutions for airports with a high share of electric aviation" (RES-Flyg) [4]. The full project will provide an overview of national and international electrification of airports and ongoing development at two Swedish airports. Also, the aim is to model energy system components (power loads, local electricity production, energy storage etc.), control strategies and interaction effects. The project will utilize different tools and methods, including tools developed in other related research project, such as the project "Infrastructure modelling for large-scale introduction of electric aircraft and air traffic control" (MODELflyg) [5]. Techno-economic estimations will support the analysis. This paper presents ongoing research in the project RES-Flyg, and work done so far.

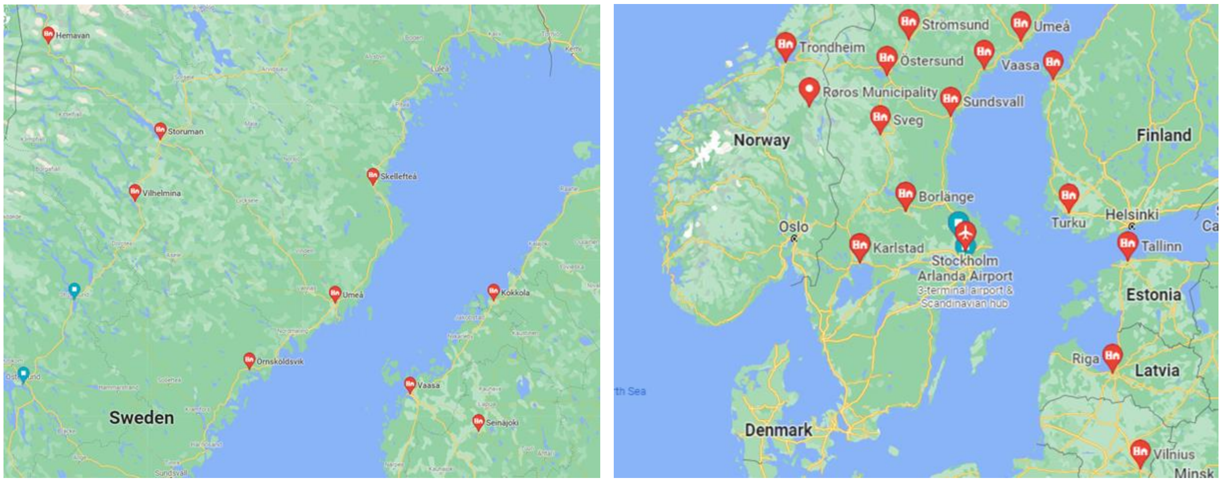
2 Background to electrification of aviation

Today, different vehicles around the airports are electrified and/or autonomous (i.e., self-driving). This was discussed in [6], where landside vehicles at airports, such as buses, bicycles, scooters, ground handling vehicles, luggage vehicles etc., were electrified or autonomous. Moreover, a rising trend at airports is to offer parking with charging infrastructure for personally owned electric vehicles (EVs). As highlighted in [7], along with the presentation of a simulation model of an electrified airport, electrified ground service vehicles on airports need sufficient charging, which affect the grid, and the charging time may be time consuming. Thus, the authors suggest that charging of ground service vehicles could be optimized in time and power at airports (i.e., smart charging) [7]. In a previous study [8], Amsterdam Airport Schiphol was the case study for increased airport electromobility, including scenarios with EVs and more renewable energy sources (RES), presenting different recommendations for electrification. When an aircraft arrives at an airport, it has a certain taxi time to the specific gate or runway, and the energy for this movement was simulated in [9] for Montréal-Trudeau International Airport, with taxi scenarios of either utilizing the jet engines of the aircraft or utilizing an additional electrified tractor to drive the plane to the runway or gate. In [3], the energy system of an airport was simulated, including PV system and hydrogen system. The opportunity of utilizing PV systems in 239 Chinese airports was outlined in [10], estimating a potential capacity of up to 2.5 GW and an annual potential of generating 2.64 TWh. The authors highlight that many previous studies have also investigated PV systems in international airports. This could support a change from using fossil fuels to RES for powering airport elevators, lights, air-conditioning, or other operations on the airports and limiting the emissions and pollution around the airports. The air quality's negative effect due to traditional fossil fuel powered aviation, resulting in adverse effects on human health, was highlighted in [11] with a case study for the South Coast Air Basin (SoCAB) region in California. Many large airports are in the SoCAB region, such as the Los Angeles International Airport (LAX). One of the suggested strategies to reduce emissions in this area is to electrify the airports' ground support equipment (GSE) [11].

Some electric aircraft developers, e.g., Heart Aerospace, aim towards routes up to about 400 km [12]. The future electric aircrafts could be suitable for densely populated regions for example in Sweden and Finland, and electric aviation was suggested for the Kvarken region [13]. Some cities in the Kvarken region that could be interesting to travel between are highlighed in Fig. 1 (a), and include in Sweden: Hemavan Tärnaby, Storuman, Vilhelmina, Lycksele, Skellefteå, Umeå, Örnsköldsvik, and in Finland: Vaasa, Kokkola-Pietarsaari and Seinäjoki. This type of travelling could enable business trips for industries, tourism, and research collaborations and education at different universities in the area [13]. As described in [14], some routes in the Northern part of Sweden and connections to neighboring countries, that could be interesting for electric aviation are presented in Table 1 with the approximate distances [km], based on analysis in [14], and the cities are highlighted in Fig. 1 (b).

Table1: Possible routes and distances (km) for electric aircraft in the Northern part of Sweden and nearby countries [14].

Possible routes	Approx. distance (km)
Between hospitals in Östersund and Umeå	288
Sveg to the airport Arlanda	330
Trondheim in Norway via Östersund to Sundsvall	375
Östersund to Sveg	128
Östersund to Strömsund	87
Östersund via Örnsköldsvik to Umeå	301
Røros in Norway to Östersund	178
Östersund via Sundsvall to Vaasa in Finland	394
Östersund via Borlänge to Karlstad	610
Östersund-Sundsvall-Åbo/Turku, Finland-Tallinn, Estonia- Riga, Latvia-Vilnius, Lithuania	1227



(a) (b)

Figure1: Cities in the (a) Kvarken region that could be interesting to reach with a future electric aircraft, where a new type of airports could enable charging, from [13], (Google Maps, accessed: 2021-12-13), and (b) interesting routes for a future electric aircraft presented in [14], (Google Maps, accessed: 2022-04-26).

The airports adapted for electric aircrafts could be smaller and include reliable access to charging. The new electrified aircrafts could be used in other ways than the traditional aircrafts, suggesting that the airport's role could be developed as well. One difference between the first planned electric aircrafts and the traditional aircrafts is the estimated number of passengers, where some developers aim towards 19 seats (or a lower number of passengers). As highlighted in [15], the main reason why developers of electric aircrafts aim for up to 19 seats, such as ES-19 under design at the company Heart Aerospace [12], is the regulations and standards: CS-23 from EASA. If more seats were added to the new electric aircraft, this would lead to the standardization of a large aircraft, which would come with more complex regulations. Thus, it is expected that the electrified aircraft will be adapted for fewer passengers and shorter distances than the traditional aircrafts today. Also, the electrified aircraft is expected to be both more environment-friendly and cost-effective. The infrastructure needed at airports may change in the future, with usage of smaller aircrafts, enabling for example faster and simpler, or even fully removed, security controls for domestic flights, and travelling shorter distances that today are suitable for mainly buses and cars, while also ensuring more battery storage than needed to ensure safety [15]. The infrastructure at the future airports must be planned to lower the risk of fire when fossil fuel driven aircrafts and charging of future electric aircrafts occur at the same airport, suggesting that the charging of electric aircrafts could be done at specific platforms [15].

3 Method and theory

3.1 Airport modelling

The project involves different types of simulations to analyse scenarios for an electrified airport. Examples of interesting scenarios are matching of electrified aircraft with scaling of a PV system and of a battery energy storage system (BESS). A model for estimating an airport load will be designed in order to simulate different scenarios. The idea is to simulate an airport load consisting of several smaller subsystems, each representing a function at the airport consuming power. These subsystems include, e.g., airport heating and cooling systems, airport activity, commercial services (e.g., shops and restaurants), aircraft charging, EV charging, BESS, PV plant etc. The different subsystems can interact or be excluded from simulations, depending on what type of scenario that is investigated. The simulation model and subsystems are built in Matlab/Simulink, with a grid frequency of 50 Hz. The output from the model is the power being consumed or produced from the subsystems at each given time-step, and the power flows from the electric grid. The chosen time-step for the input data of the model is one minute, but it is also possible to use larger or smaller time-steps for better accuracy or shorter simulation times. A one-minute resolution was chosen as this resulted in a decent data resolution yet with a reasonable simulation duration that allow iteration of different scenarios. The model is built to focus on power balances and is not examining the power quality of the system such as harmonics, transients, etc. The goal of the initial simulation model in Matlab/Simulink is not to make a case specific and highly accurate model, but more so a generic model that indicate the power need of a future electrified airport. Only a few design parameters are included. The design parameters used as input data are presented in Table 2. It is also possible to add more subsystems for other functions, such as power consumption of shops and restaurants. The model, visualized in the sketch in Fig.2, will be utilized with input data from Skellefteå Airport and Visby Airport.

Table2: Input data for each subsystem. The names of the subsystems are on the first row, and each column briefly describes the input data for each respective subsystem.

PV plant	Battery	EV chargers	Aircraft chargers	Heating and cooling
PV area [m^2]	Rated power [kW]	Number of EV charger [#]	Load profile from MODEL-Flyg	Type of system (heat pump, non-electric etc.)
Local solar irradiation profile [W/m^2]	Rated capacity [kWh]	Average charge time [min]	-	Heated building area [m^2]
PV Efficiency [%]	Efficiency [%]	Charging power for one charger [kW]	-	Building height [m]
Weather conditions [Cloudy/Sunny]	Load limits for charge/discharge [kW]	Expected number of EVs arriving [#/min]	-	Reference indoor temperature [°C]
-	Limits, battery SoC [%]	-	-	Airport activity or passenger flow [#/hour]
-	Initial SoC [%]	-	-	-

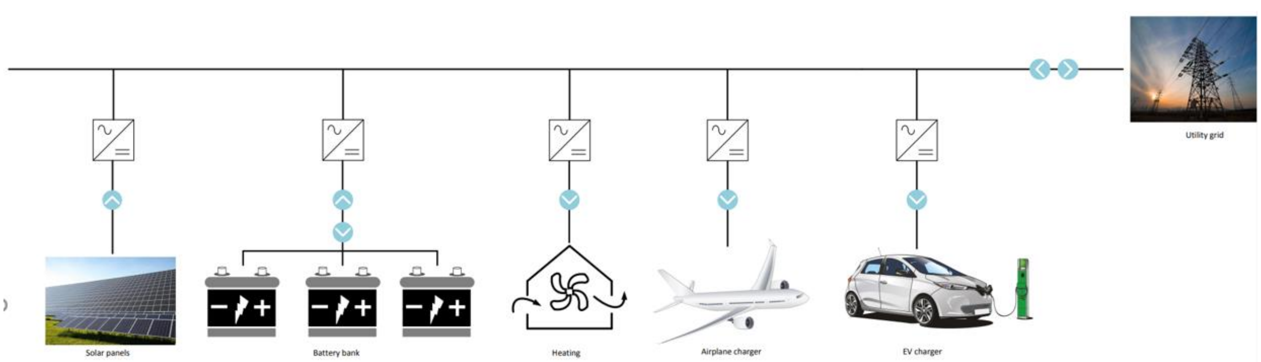


Figure 2. Sketch of the set-up of a proposed model in Matlab/Simulink for loads at the airport.

3.2 Energy system modelling

A prerequisite for sustainable airport electrification is the availability of local renewable electricity generation. Because of the technical properties, solar PV could be an interesting solution, and examples are found nationally and internationally of on or near-site airport installations. The case studies in this project are modelled with different designs of the on-site PV array(s). Additionally, electrical battery storage systems are included, and their effect is examined by varying their size and charge/discharge control. The PV and battery modelling is done in Python with the required data inputs, and examples of resulting outputs are presented in Table 3. The load demand and PV generation profiles are the time series from a full year's operation, and the peak power tariff(s) also includes information about the billing structure stating on- and off-hour prices. From the site drawings of the airport, estimates of PV array sizes are done based on the available space.

Table3: Required input data and resulting output data from the PV and battery modelling in Python.

Input	Unit	Output	Unit
Load demand	W	PV generation	W
Electricity price (bought and sold)	SEK/kWh	Electricity import/export	Wh
Peak power tariff(s)	SEK/W	Peak shaving potential	W
Site drawings	-	Electricity bill (savings)	SEK

3.2.1 Solar photovoltaic system design

For a PV installation in Sweden, a tilt angle (from horizontal) of 41° is estimated to generate a high annual energy yield [16], resulting in a peak output during mid-day. However, if this output is poorly correlated with the energy demand, and without the presence of storage, it will result in a peak power export to the grid and thus increase the stress, or worse, result in power curtailments. Optionally, the PV array design can be done to match the energy demand and thus increase the self-consumption rate and thus reduce the grid interaction [17]. In this project, both options, maximized yield and load-matching, will be used for designing the PV systems for each case study.

3.2.2 Battery storage system charge and discharge control

A commonly used battery control (dispatch) strategy for charge and discharging has the objective function to maximize the self-consumed (locally generated) electricity and is typically used for a combined PV and battery system [18]. This dispatch charges the battery from PV surplus and discharges when the load demand exceeds the PV generation. A drawback with this dispatch is the fact that it relies on excess generation, and a study from a Sweden case has shown that during the winter, the battery remains redundant [19]. Other examples of objective functions for battery storage include peak shaving, which uses the battery to reduce peak imports, and price arbitrage operation using the variation in electricity price. In Sweden, the electricity spot prices are set for the coming 24 hours on the Nord Pool market [20], making it possible to foresee the pricing, but the intra-day variations need to vary significantly to generate revenues considering the ware on the battery.

Previous works in PV and battery systems for residential purposes have acknowledged the need for multi-objective battery operation for investment attractiveness [21,22]. In this project, two battery dispatch control strategies are modelled and compared for the two case studies: (i) maximizing self-consumption and (ii) a multi-objective dispatch control combining self-consumption with peak shaving and price arbitrage.

3.2.3 The potential risk of photovoltaic systems in airports

Installation of the solar power system at the airport brings new challenges that might compromise the safety of air transport [23]. Given airports' safety and security, analysis of such risks and mitigation plans are an important part of the project. In a report [24] presented by the Swedish Electrical Safety Agency (Elsäkerhetsverket) and the Swedish Armed Forces (Försvarsmakten), solar installations and required system are mentioned as a source of interferences. Moreover, the reflection of light from solar panels can impose a hazard on air traffic. Therefore, analysis is required to ensure that solar installations will not create hazardous glare [25]. Due to such potential risks and lack of knowledge and clear standards, the installation of solar panels at airports is prohibited in some cases. This study aims to develop a process to systematically map the potential for local renewable electricity supply with solar cells, given the airport's specific conditions. Special requirements imposed on photovoltaic installations will be identified and possible measures and strategies will be proposed to avoid and eliminate potential risks.

4 Case studies of electrification of Swedish airports

The goals in Sweden are to have all domestic aviation free from fossil fuels by 2030 and all aviation fossil-free 2045 [26]. Many airports in Sweden have already removed [27], or reduced, fossil fuels from other vehicles at the airports. The electricity prices in Sweden differ within the country. Two case studies will be included on the electrification of Swedish airports; Visby Airport, operated by Swedavia [28], and Skellefteå Airport [29]. Visby Airport is located on the Swedish island Gotland, in the Southern part of Sweden, whereas Skellefteå Airport is located in the Northern part of the Swedish mainland. The authors will visit both airports within the project time and investigate opportunities for electrification. The aim is to investigate and model, e.g., battery energy storage, PV systems, different loads, estimated power need for future electrified aircrafts and charging infrastructure needed for complete electrification of the airports. Based on data and modelling, different energy system optimization strategies will be tested to dimension energy storage and photovoltaic power. Within the project, there will be evaluations and considerations to regulatory requirements, safety concerns and possible disturbances posed by solar systems and electromobility components in an airport. Also, full investment costs of electrifying the studied airports can be estimated.

4.1 Visby Airport

The distance between Visby on the island Gotland and the capital Stockholm allows for travelling with a future electric aircraft. It is about 189 km from Visby Airport to Bromma Airport and 225 km from Visby Airport to Arlanda Airport, and it is estimated that the electric grid infrastructure available today could be enough to start with for smaller electrified airplanes from the Stockholm region to Gotland, but, grid reinforcements may be needed [15]. The destinations are marked in the map in Fig. 3. Electric aviation could be interesting for Gotland as there is no road transport from the mainland to the island (i.e., there is no bridge in-between). The power company at Gotland is Gotland Energi AB (GEAB), and there is a focus on a transition towards significantly more renewable energy systems on the island [30]. Utilizing more EVs on Gotland has been of interest [31]. At Gotland, there is a specific security situation.

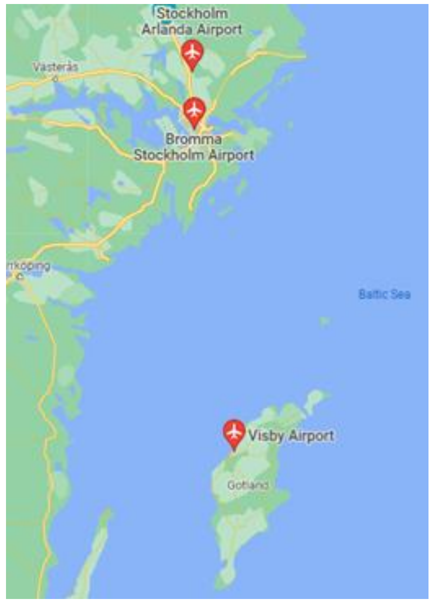


Figure 3: (Google Maps, accessed: 2021-12-13).

4.2 Skellefteå Airport

Skellefteå Airport is in the North of Sweden. Here, companies such as NorthVolt and Skellefteå Kraft have created a focus on energy systems. The distances between the cities in the North of Sweden are typically larger than in the South, the number of inhabitants is lower in the North of Sweden, and there are also areas with lower availability and accessibility of public transportation, such as trains. A big part of the electricity generation, mainly from hydropower, comes from the Northern part of Sweden and there is good availability of electricity in the vicinity of Skellefteå Airport. Skellefteå Airport has ensured access to 1 MW for charging electric aircraft, delivering 12 kV. The airport has already two-seated battery-electric planes of the type Pipistrel. An aircraft at Skellefteå Airport is shown in Fig. 4.

Figure 4. Electric aircraft for two passengers at Skellefteå Airport.

During the covid-19 pandemic, the number of passengers at Skellefteå Airport decreased, as highlighted in [32], from 408 980 passengers in 2018, to 287 079 passengers in 2019, and 94 689 passengers in 2020. This, while the electricity utilization was more similar as previous years but a little lower in 2020 than in 2018, resulting in a higher electricity demand per passenger. The total electricity need at Skellefteå Airport was 1 537 800 kWh in 2018, 1 476 200 kWh in 2019 and 1 248 900 kWh in 2020. In 2018 the energy used per passenger was 3.8 kWh, in 2019 it was 5.1 kWh and in 2020 it was increased to 13.2 kWh [32]. The energy usage was typically higher at the airport during the colder months (e.g., October to March) than in the warmer months (e.g., May to September) [32].

The routes from Skellefteå Airport with a small, electrified aircraft could combine parts of the Northern region to ensure access to hospitals, universities, industries, and tourist activities. The distances would be shorter than the trips with a traditional aircraft and could be utilized instead of commuting with buses. The routes could better connect the Northern part of Sweden with the Southern parts. Possible routes for electric aviation may also create connections between East and West, connecting regions in the North of Norway, Sweden, and Finland. The aircrafts would however not have very many passengers, for example a maximum of 19 seats in a ten-year perspective. This could generate new business models for how to book a trip, when to charge or discharge the aircrafts and which cites to visit.

5 Discussion and conclusions

The project “Resource-efficient energy system solutions for airports with a high share of electric aviation” is currently ongoing, including collaboration between researchers from RISE and Uppsala University. Data from the airports for the specific case studies, Skellefteå and Visby Airports, are currently gathered in dialogue and the authors aim to visit both airports in the Spring of 2022. Within the project, different simulation models, in e.g., Matlab/Simulink and Python, will be further developed and utilized for data relevant for Visby Airport and Skellefteå Airport.

With new electric aircrafts, the electricity and charging demand at the airports will increase. It is not only the aircrafts that are expected to be electrified in the future at and around the airports, suggesting an increase in electricity usage. Due to local variations of electricity prices in Sweden, electrification of full airports can result in different costs for different airports. Also, the use of local electricity production from e.g., wind or solar power could be more beneficial or suitable for some airports and regions. There are companies working towards designing electric aircrafts, such as the company Heart Aerospace, with development in Sweden. Electrification of aviation suggests that the national grid should be reinforced to ensure a secure access to electricity, where the aviation sector is one of several areas in Sweden undergoing electrification. It is concluded that the electrification of Swedish aviation, according to national goals, will require technical development of aircrafts, batteries, electric motors, charging infrastructure etc., and development of airports. Long distances between different cities in Sweden suggest that the transportation infrastructure is highly important, and that there is an interest in ensuring sustainable aviation in Sweden. With the ongoing project, “Resource-efficient energy system solutions for airports with a high share of electric aviation”, there is an aim to contribute with small steps towards electric aviation.

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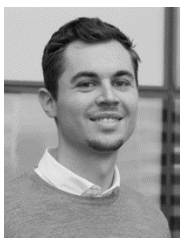

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