Solar energy for self-sufficient electric aircraft operations at Bardufoss flight school

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Abstract

Electric transport powered by renewable energy is key to reduce the climate impact of the transport sector. Significant resources are put in to developing larger electric and hybrid-electric passenger aircraft, but the first electric aircraft will be small and short-range. Flight schools are well set to be early adopters of electric aircraft. This paper presents the experiences from the first year of operation of electric aircraft at University of Tromsø School of Aviation (UTSA) in Bardufoss in Northern Norway. A façade-mounted 100 m^2 PV system at the airport provides power to the aircraft. First year measurements show an energy yield of 618 kWh/kWp. If the aircraft were used in regular pilot training (which they are not due to their status as "Experimental) the system could supply energy for around 700 flight hours with the electric aircraft, giving an annual self-sufficiency of the operations of 0.83.

Keywords: self-sufficiency, solar airports, electric aircraft

1. Introduction

The transport sector is one of the major contributors to greenhouse gas emissions globally and in Norway. In Norway, the transport sector accounts for 24% of the energy demand, but 33% of the greenhouse gas emissions (OED, 2021). Electric transport powered by renewable energy is a key to reduce the sector's climate impact. Other technologies, such as hydrogen fuel cells and sustainable biofuels, are also part of the solution. Electric vehicles for road, rail and sea transport are becoming more and more widespread, but aviation is one of the most difficult sectors to electrify due to the weight restrictions, high safety requirements and because it is impossible to charge during operation. There are now over 200 research and development projects around the world involving electric aircraft (Thomson, 2020). Although significant resources are aimed at developing larger electric and hybrid-electric passenger aircraft, the first certified electric planes will doubtless be small, short range, and operate low-passenger routes.

Flight schools are well suited to be early adopters for electric aircraft. Most training flights are relatively short with only one student and one instructor. This is proven by the interest in the he all-electric eFlyer, a 2 or 4 seat training aircraft which is currently in development by Bye Aerospace (Bye Aerospace, 2021). The aircraft has already been pre-ordered by among others OSM Flight Academy, Reykjavik Flight Academy in Iceland, and KLM Flight Academy in the Netherlands (Future Flight, 2021). Since electric aircraft are less costly to operate and require less maintenance, there are also economic arguments for switching to electric training aircraft.

A widespread adoption of electric aircraft will require significant amounts of power for charging. In addition, aviation includes more than the aircraft: A fully electric aviation sector will also contain vehicles and services on the airport side, such as cars, buses, fire trucks, snow removal, catering, cleaning, and de-icing, and possibly also charging infrastructure for transport to and from the airport, such as buses, taxis and personal vehicles (Energi Norge, 2020). In addition, there is the power requirements of the operation of the airport buildings.

Airports are often well suited for solar energy installations, with large available building areas and little shading from the surroundings (Kandt and Romero, 2014). Solar energy is therefore set to contribute to low emission aviation. However, strict safety considerations for airport installations are important to ensure that the installations do not disturb or interfere with aircraft operations. In particular this is related to avoiding glint and glare, but there may also be other safety issues concerning the distance from the airport or fire hazard (Kandt and Romero, 2014). The Federal Aviation Administration (FAA) in the United States has recently issued a policy for safe solar installations at airports (FAA, 2021).

This paper presents the experiences from the introduction of electric aircraft powered by local solar energy at University of Tromsø School of Aviation (UTSA) in Northern Norway. UTSA is a part of UiT The Arctic University of Norway operates out of Bardufoss airport in Northern Norway. The flight school admits 24 students yearly to the

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bachelor's programme in Aviation, where the students also gain a Commercial Pilot License (CPL).

Bardufoss is located north of the Arctic Circle and has polar night between 30 November and 12 January, meaning that the sun does not rise above the horizon. Conversely, the period with midnight sun, when the sun never sets below the horizon, ranges from 23 May and 1 July. The available solar resource is therefore very unevenly distributed over the year. The location in Northern Norway also means that the weather conditions can be harsh, especially during winter, and the topography challenging. This puts special demands on both pilots and equipment.

2. Method

2.1 Electric aircraft

In 2018, UiT and UTSA bought two small electric aircraft of the type Pipistrel Alpha Electro (Fig. 1, left) as part of a research project on electric aviation. The two-seater aircraft can carry a total load (pilot and passenger) of 180 kg, with an endurance of around 1 hour plus safety margin. The aircraft are powered by a 60 kW electric engine and have a battery capacity of 21 kWh (Pipistrel, 2018). According to Pipistrel, the batteries are designed to be easily and quickly replaced or charged in less than an hour. In practice, the batteries are charged using a portable 20 kW charger.

Due to issues with the battery, only one of the aircraft (LN-EON) has so far been airborne. The aircraft has logged around 45 flight hours around Bardufoss Airport and gathered data for research. Among the objectives are to study the energy performance of the aircraft in at different conditions and types of operation, battery life and degradation, as well as requirements on airport infrastructure for electric aviation. An additional focus is operations in Arctic and northern conditions, including difficult topography and harsh weather conditions.

Fig. 1: One of the two Pipistrel Alpha Electro aircraft at Bardufoss Airport. Photo: Tomas Rolland, UiT.

As in all aircraft operations, safety is an overarching focus. The aircraft were originally intended to be used in regular training at the flight school, but this has not been possible since the Alpha Electro is still classified as "Experimental" and therefore not certified for regular operation. The planes are therefore only flown by specially trained flight instructors at UTSA, using strict safety protocols. Last year, however, Pipistrel launched the Velis Electro, which is an EASA (European Union Aviation Safety Agency) certified version of the same aircraft frame (Pipistrel, 2021). Other electric trainers are also set to be certified. Bye Aerospace, for example, has projected to have certification of its eFlyer 2 by the end of 2022, or possibly even earlier (Future Flight, 2021).

The calculations in this study are made for an imagined scenario where the aircraft are used in ordinary pilot training. In this scenario, it is estimated that they would fly two training rounds per day each, giving a total of four daily flight hours. Since the Alpha Electro lacks de-icing capabilities, the aircraft are only operated in conditions without risk of icing, and it is estimated that this period lasts from April to October. In total, this means 846 flight hours per year.

2.2 Solar energy system

A photovoltaic (PV) solar energy system (Fig. 2) was installed at the airport to provide local renewable power to the electric aircraft operations. The 100 m^2 PV system was installed on the south-facing wall of UTSA's hangar building, directly facing the air strip. The system consists of 58 modules with a total installed power on 19.2 kWp. The modules are 330 Wp monocrystalline half-cell modules from JA Solar (JAM60S10-330-PR-SF). The system is connected to the grid via a 15 kW Ginlong Solis inverter (SOL-15.0-3PH-4G-DC).

Fig. 2. The 100 m² photovoltaic system at Bardufoss Airport. Photo: Clara Good.

When installing the system, it was discussed whether modules should also be placed on the roof of the hangar. An installation on both roof and façade would have made possible a larger installation, and the solar energy would have been more evenly distribution of energy over the day and year. The roof-mounted option was eventually not chosen for two main reasons. Firstly, there were uncertainties about the durability of the construction, and whether it would be able to hold the extra weight in addition to the already high rated snow load. The second reason was uncertainty regarding reflections from modules, and how this might affect the air traffic. As mentioned in the introduction, there are now guidelines and policies for how to safely install PV systems at airports (FAA, 2021, Kandt and Romero, 2014), and it might be possible to extend the installations to the roof a proper analysis of the consequences.

Vertical installations, such as on building facades, is generally a good option in northern regions, since the sun angle is relatively low. The maximum sun angle in Bardufoss is around 45° during summer, and it is lower in spring, winter and autumn. Another benefit of vertical installations is that it reduces the problem of snow accumulating on the modules, which may lead to reduced energy yield, and in extreme cases also structural damage to the modules.

2.3 Solar self-sufficiency

One of the objectives of the PV installation at the airport was for the operation of the electric aircraft to be self-sufficient on local renewable energy. That is, that the solar energy generated by the PV system would be enough to power all operation of the electric aircraft throughout the year.

Solar self-sufficiency can be defined as the self-consumed part of the solar energy yield relative to the total load (Luthander et al., 2015). It follows that even though two systems may have the same self-consumed energy in absolute terms (kWh), their relative self-sufficiency can be different if the total load is different. Using the terminology from Luthander et al. (2015), the solar fraction can be described by

$$\varphi_{ss} = \frac{\int_{t=t_1}^{t_2} M(t)dt}{\int_{t=t_1}^{t_2} L(t)dt}, \qquad \text{(eq. 1)}$$

where $M(t)$ is the instantaneously overlapping part of the PV generation, $P(t)$, and the load, $L(t)$, defined by

$$M(t) = \min\{L(t), P(t)\}. \qquad \text{(eq. 2)}$$

In addition to the load and generation profiles, the self-sufficiency depends, among other things, on the time resolution t and the period of integration. In the analysis presented here, the time resolution is one month, and the period of analysis is one year. In further analyses of the data, the calculations will be made for a smaller time resolution, e.g. one hour, and a battery storage may also be introduced.

In addition to the monthly and yearly self-sufficiency, the number of generated flight hours are calculated. In this case, calculations are performed also for the months when there are no operations due to risk of icing.

3. Results

3.1 Electric aircraft performance

The aircraft at UTSA are operated with a safety margin of 20% battery reserve, that is, the required state of charge (SOC) at landing. The aircraft has so far been flown in training patterns with varying power requirements. Based on the experiences of the pilots so far, a very rough estimate is that the endurance during a "normal" flight from A to B in good weather conditions is 1 hour plus safety margin, giving an estimated energy performance of 16.8 kWh per flight hour, based on a battery capacity of 21 kWh.

In the scenario where the aircraft would be incorporated into normal operation at the flight school, with four flight hours per day, the energy demand is 67.2 kWh per day. Assuming operation from April to October, the total annual energy demand of the aircraft would be 14381 kWh, or on average 2054 kWh per month.

Assuming that the four flights would be distributed throughout the day, the energy demand would be distributed over four charging sessions. A very simplified distribution is presented in Fig. 3. In reality, it may be that especially the two later charging sessions of the day would be done at lower power, in order to preserve battery health. It could also be that the charging sessions would be planned based on the available solar energy, or the charging level of an external battery storage.

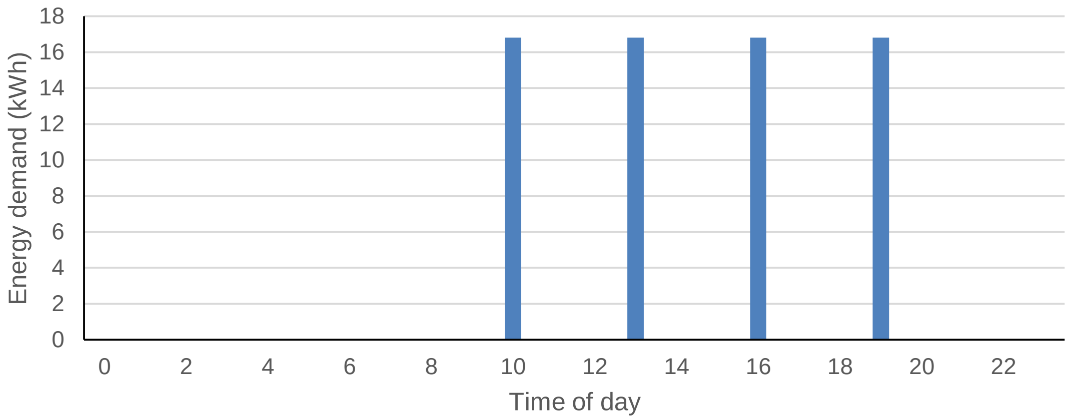

Fig. 3. A simplified version of the hourly energy demand for charging the electric aircraft.

Analysis of the gathered flight data will be used to determine a more detailed understanding of the energy performance in different types of operation. This is a topic for current and future research.

3.2 Solar energy generation

The PV system at Bardufoss has been operational since November 2019. The total measured solar energy yield during 2020 was 11872 kWh or 618 kWh/kWp, which was very close to estimations. The monthly distribution in 2020 is shown in Fig. 4, which also includes measurements up until September 2021. If the yield in the remaining three months of 2021 is the similar to that in 2020, the total energy yield in 2021 will be 11812 kWh, or 615 kWh/kWp.

The location above the Arctic Circle is reflected in the data in Fig. 4. The energy yield during the polar night in November, December and January is close to zero. The longer days and midnight sun during summer do not have a large effect on the energy yield of the systems since it is façade-mounted and facing south, which means that the sun is behind the modules for a significant period of each day. However, as the values for June show, the weather-related difference between years can also be substantial: the energy yield in June 2020 was 45% higher than the energy yield in June 2020.

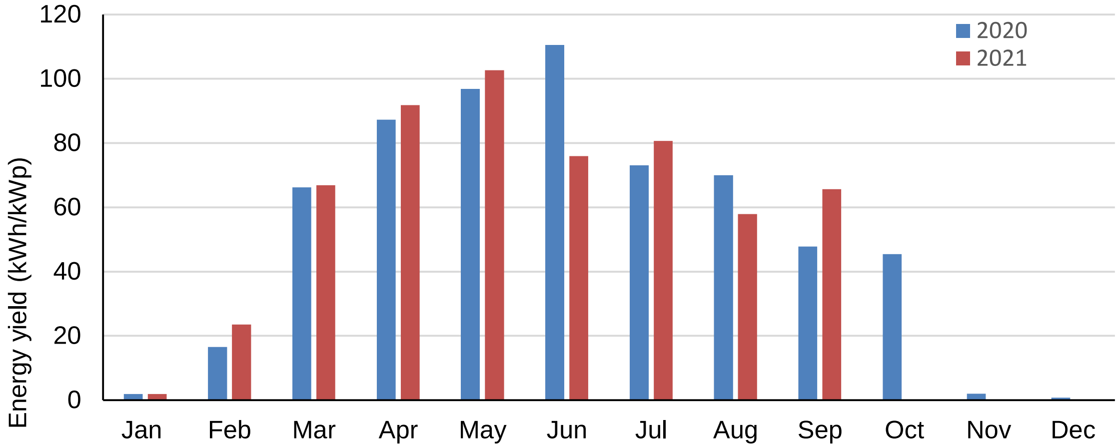

Fig. 4. Monthly energy generation from the PV system in 2020.

As expected, the spring months have a quite high yield. During March and April, it is still quite cold, which increases module efficiency, and the sun angle is generally low, which is suitable for vertical system. In addition, there may still be snow on the ground, which reflects the sunlight.

3.3 Solar self-sufficiency

The monthly level of self-sufficiency (in percent) of the electric aircraft operations is shown in Fig. 5. The average self-sufficiency during these months were 0.70. With the PV energy yield in 2020, the annual self-sufficiency would have been 0.83. In June, the generated energy covered 105% pf the demand (but the self-sufficiency cannot, by definition, be higher than 1). This calculation of the net self-sufficiency assumes grid-connection of the PV system, and that energy can be exchanged with the grid at any time. Further calculations will focus on the temporal load match between solar energy and charging load at higher time resolution, and thereby the possibility to operate on solar energy without exchanging energy with the grid.

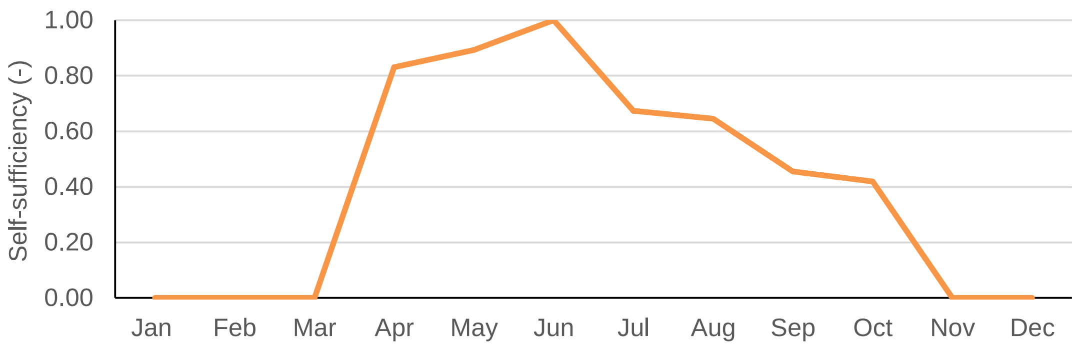

Fig. 5. The monthly level of self-sufficiency oft he electric aircraft operations, shown in percent.

Given the estimated energy requirements and the energy yield of the PV system, and disregarding the load match, the system generated enough power for 707 electric flight hours in 2020. The energy was, however, very unevenly distributed over the year, with enough for 126 flight hours in June, and only 5 in total from November to January. The average number of flight hours that it would be possible to fly with the energy from the PV system are given in Tab. 1, as average values for each month. The values for 2021 in the Tab. 1, 126.3 hours in 2020 and 86.8 hours in 2021, also shows the large difference that may occur between years.

Tab. 1. The daily flight hours that would be possible with the energy from the PV system, given as average values per month.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daily flight hours 2020	2.2	18.9	75.7	99.7	110.7	126.3	83.5	80.0	54.6	52.0	2.3	0.9
Daily flight hours 2021	2.2	26.8	76.4	104.9	117.4	86.8	92.1	66.2	75.0	-	-	-

4. Discussion and conclusions

Flight schools can be early adopters of electric aircraft. In addition to a reduction in greenhouse gas emissions, introduction of electric aircraft has the potential to significantly reduce operating costs. Since airports are often well suited for solar energy installations, it is interesting to study the possible solar self-sufficiency of electric flight operations. With the current PV installation at Bardufoss, the annual energy yield in can provide around 80% of the required energy for operations with two electric aircraft, had they been used in normal training operations

For the flight school, the load-match between solar energy and flight operations, in particular electric aviation, is relatively good since most flying is done during daytime in the summer. The two electric aircraft at the flight school are not operated in cold conditions, due to the lack of de-icing capability. During the normal operation period, the average monthly self-sufficiency was 0.7. However, there may be large differences between years.

There are several possibilities to increase the solar self-sufficiency of this particular system. More PV modules could be added to the building, also at different orientations, a battery could store energy to provide direct charging without grid-connection, and the charging of the electric aircraft can be scheduled to best coincide with available solar energy.

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