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Zero emission airport, OSL Gardermoen – future energy use and combination of energy carriers.

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Renewable Energy

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Lenka Ouro Akpo Vrabel
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Abstract

In the last decades, the entire world has been grappling with climate change challenges. The main reason for climate change is increased concentration of greenhouse gases in the atmosphere, caused by burning fossil fuels. The aviation is also responsible for increasing global CO2 emissions. The most discussed solution to emission reduction in recent years is electrification. However, will this solution lead to increased electricity demand? Hence, we decided to examine three scenarios on the case study of OSL Gardermoen, that may represent a solution in the future. The first scenario includes domestic electric aviation on four routes (Stavanger, Bergen, Kristiansand, Trondheim), while second scenario focuses on single hybrid aircraft route to Bodø. The third scenario explores the hydrogen aircraft solution for international flights.

The total future electricity demand of OSL Gardermoen was modelled for all three scenarios based on calculations of: charging pattern of electrified ground services; charging pattern of electric aircrafts, hybrid aircraft and hydrogen aircraft; flight schedules and number of passenger seats.

Scenario I resulted in an increase of 132 GWh, which represents 112% yearly rise in electricity demand at OSL Gardermoen

The yearly electricity demand in Scenario II increases by 158.29 GWh/year, which represents increase of 130% compared to actual electricity consumption.

Scenario III resulted in yearly increase of 421,53 GWh. When all three scenarios are combined, the annual electricity demand of OSL Gardermoen increases by 558,22 GWh/year, which represents increase of 459% compared to actual electricity consumption.

In conclusion, while electrification combined with hybrid solutions shows promise in reducing emissions and noise pollution in aviation, the challenges of managing increased electricity demand, technological uncertainties, and the need for broader infrastructure improvements remain significant areas for further research and exploration in the pursuit for sustainable aviation solutions.

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List of Abbreviations

NMBU	Norwegian University of Life Sciences
UNFCCC	United Nations Framework on Climate Change
GHG	Greenhouse Gases
CO2	Carbon Dioxide
CO2-eq	Carbon Dioxide - equivalent
GW	Giga Watt
kWh	Kilo Watt Hour
MWh	Mega Watt Hour
GWh	Giga Watt Hour
TWh	Terra Watt Hour
PJ	Petajoule
km	kilometer
min	minute
SAF	Sustainable Aviation Fuel
OSL Gardermoen	Oslo Gardermoen Airport
SAS	Scandinavian Airlines
ZERAC	Zero Emission Regional Aviation Conference
DNV	Det Norske Veritas
CORSIA	Carbon Offsetting Scheme for International Aviation

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1.0 Introduction

In the last decades, the entire world has been grappling with challenges associated with the man-made climate change. The main reason for climate change is increased concentration of greenhouse gases (GHG) in the atmosphere, caused by burning fossil fuels (United Nation Climate Action, 2023). In 2022, GHG emissions from aviation including international air transport in Norway totaled 2,69 million tones CO2-eq (SSB, 2023). Aviation holds vital significance in Norway, playing a crucial role not only in supporting export industries, general business, and tourism but also in providing essential transportation services in remote areas where people depend on air transport (AVINOR, 2022). Given the substantial role aviation plays in Norway, it is emergent to identify and develop prospective solutions that align with future needs and demands in this sector, notably emphasizing emission reduction.

The most discussed solution to emission reduction in recent years is electrification. However, aviation is considered as a hard-to-electrify sector and complete transition to electricity may not be feasible (DNV TRANSPORT IN TRANSITION, 2023). Hence, it is necessary to explore alternative measures that can supplement the electrification process. The cost-effective approach to complement electrification resides in the utilization of sustainable aviation fuel (SAF) (DNV,2023). The integration of hydrogen as a fuel source in aviation remains relatively new but is gaining traction as an increasingly feasible and environmentally sustainable option within the aviation industry (DNV TRANSPORT IN TRANSITION, 2023). However, the problem arises not only in the transformation of aviation itself, but also in changing the airport's infrastructure to facilitate electrification and the use of SAF and hydrogen (Alfredsson et al., 2022).

Norway has ninety-eight certified airports, of which AVINOR, the government's airport operator, owns 45 (AVINOR, 2023). Oslo Airport Gardermoen (OSL Gardermoen) is one of the busiest airports in the country and half of all flights are international, producing the most emissions (Wikipedia, 2023a). To reduce emissions, AVINOR has determined that its own activities (airport operations) will be fossil-free by 2030. Norwegian aviation industry has requested all short-haul flights lasting up to 1.5 hours to be electric by 2040, and all Norwegian air traffic to be fossil-free by 2050 (AVINOR, 2022; World Economic Forum, 2018). The ambitious initiatives proposed by AVINOR, and the Norwegian aviation industry prompt the following research question:

Electricity demand of a zero-emission airport - case study of OSL Gardermoen.

2.0 Background

This chapter consolidates and presents an overview of the research and conclusions documented in existing literature, addressing the research question of this thesis. For better understanding, the overview presents Norway's energy system, explores the intersection of aviation with international and national climate change agreements, and outlines potential strategies for decarbonizing aviation. Specifically, it involves exploring electrification, sustainable aviation fuel, and the utilization of hydrogen as viable solutions.

2.1 Energy system in Norway

Norway is renowned for its renewable energy production. The hydropower covers 90 percent of the Norwegian power supply, which equals approximately 136,4 TWh a year. Production from wind power plants depends on weather conditions and can correspond to 13,1 TWh in a normal year (Energi fakta Norge, 2021).

Enormous potential of 338 GW for offshore wind power along the entire coast was shown by Multiconsult study (2023). The government's target for offshore wind power is 30 GW by 2040 (Multiconsult, 2023). Moreover, the possibility to store CO2 makes Norway perfect candidate to reach first fully renewable energy system in the world (Ouro Akpo Vrabel, 2022).

However, to fully reach renewable energy system, there is a need for more variability and flexibility. The flexibility in the current system is provided by hydro power plants with storage reservoirs, as well as by fossil fuels such as oil and natural gas. Fossil resources are convenient for their on-demand use and easy storage, but they are not sustainable in the long term (Ouro Akpo Vrabel, 2022). Given the projected surge in electricity demand, there is a need to replace fossil fuels with alternative energy sources.

2.1.1 Prognoses of power demand

The latest study by Statkraft shows the significant increase of power demand in Norway towards 2030 and 2050. The increase of power demand in all projected scenarios stems from the anticipated growth in industry and transport, fueled by both direct and indirect electrification. The model forecasts show that by 2030, the average power production in Norway will increase by 9-22%. By 2050, the projected power production will reach an increase of 31-73%. (Lavutslippsscenario Norge, 2023).

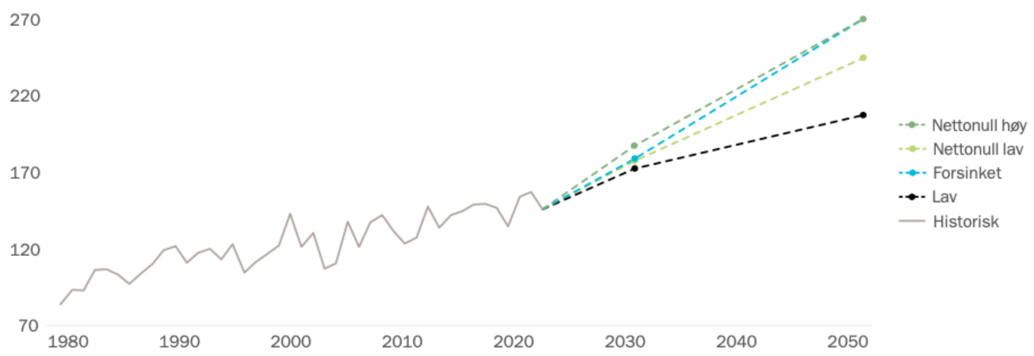

Figure 1: Norwegian power production today, 2030 and 2050 - different scenarios (TWh), (Statkraft, 2023).

DNV's Energy transition outlook (2023) coincides with Statkraft study (2023) and anticipates increased consumption of electricity. Furthermore, the DNV's Energy Transition report for Norway (2023) informs about the distribution of energy carriers in the future.

Electricity grows continuously while e-fuels and hydrogen get significant uptake around 2040 (DNV Norway, 2023). A closer look at the energy transition in aviation indicates that oil will continue to be the most used energy carrier. However, a visible increase in the share of electricity, bioenergy and E-fuels will begin around 2040 (DNV Norway, 2023).

Examining Figure 2 reveals that there is not a single ideal solution. Hence, our approach for zero emission airport, focusing on exploring various options and combinations of carriers, is therefore suitable.

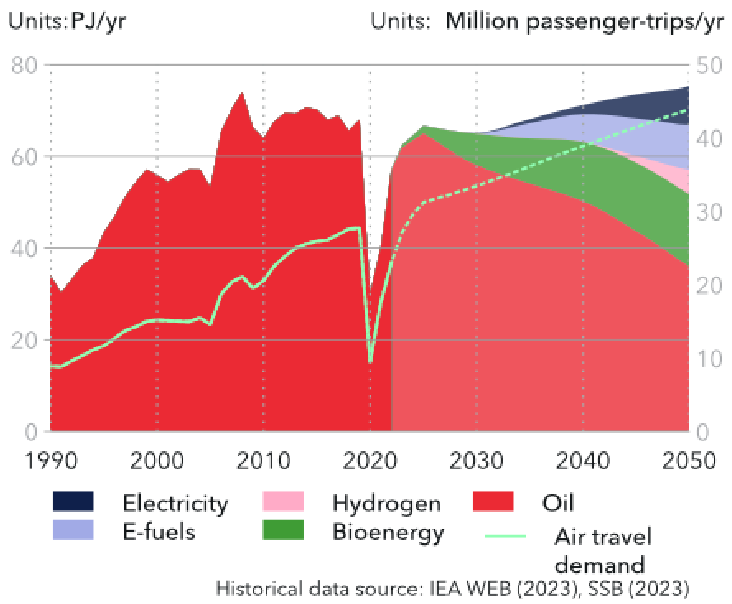

Figure 2: Norway aviation subsector energy demand by carrier, (DNV Norway, 2023).

2.2 Aviation within international and national climate change agreements

The United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1992 with the aim of preventing dangerous human interference with the climate system. This laid the foundation for the legally binding global climate change agreement, known as The Paris Agreement, which was established in 2015 (United Nations Climate Change, 2023).

Norway is one of the 194 countries that have committed to the goal to limit global warming to 2°C, preferably no more than 1.5°C, compared to pre-industrial times (European Council, 2022). Norway likewise submitted an enhanced climate target to cut emissions by 55 percent by 2030 (Regjeringen, 2022).

Norway's biggest emissions sources are oil and gas extraction, industry, road traffic and other transport. The category "other transport" includes aviation, which represents 7,7-million-ton CO2-eq per year (Miljøstatus, 2022). However, mitigating emissions resulting from aviation poses a substantial challenge.

Therefore, in 2020 joined Norway the United Nation's International Civil Aviation Organization's program of carbon-neutral air travel growth, called Carbon Offsetting Scheme for International Aviation (CORSIA) (ICAO, 2023). CORSIA is a global market-based measure to keep international aviation-related carbon dioxide emissions at 2020 levels by obtaining the carbon offset units through the worldwide carbon market (ICAO, 2023).

Norway actively engages in international agreements and initiatives while undertaking endeavors at the national level to implement measures in alignment with scientific and policy frameworks. AVINOR emphasized the significance of enhancing efficiency in Norwegian airspace; integrating electric and hybrid aircraft; and transitioning to sustainable aviation fuel to achieve the objective of fossil-free aviation (AVINOR, 2022).

Furthermore, AVINOR has together with the Norwegian Civil Aviation Authority, SINTEF, and the Federation of Norwegian Industries, established the Green Aviation Program. The initiative aims to support the advancement and secure integration of zero and low-emission technology, as well as to protect regulatory conditions for early-stage aircraft development (AVINOR, 2022).

2.3 Possible solutions

The pressure to decarbonize the aviation is tremendous. The public as well as the authorities expect prompt solutions, but from the technological point of view, the options for substituting conventional aviation fuel are limited. Aviation is considered as a hard-to-electrify sector and complete transition to electricity may not be feasible, but there is a growing anticipation that this could become achievable, especially for regional flights and certainly for smaller aircrafts (Alfredsson et al., 2022, s.4; Reimers, 2018, s.6). SAF has already integrated into the aviation sector but the non-mandatory implementation of SAF refueling, attributed to the absence of legislative measures by governmental and regulatory bodies, continues to contribute to economically unviable prices (DNV, 2023).

The utilization of hydrogen within aviation remains relatively new, yet it's progressively considered as a feasible choice for making the sector more sustainable (DNV TRANSPORT IN TRANSITION, 2022).

Aviation faces a formidable challenge in implementing zero-emission technology, as it requires overcoming potential limitations rooted in technological constraints. Substantial advancements in all mentioned alternative energy sources are necessary to address this challenge.

2.3.1 Electrification

The most discussed solution to emission reduction in the last years is electrification. The recent progress in battery technology, with annual increase in the energy density around 3-4%, has sparked interest among aircraft developers for the future of aviation (Schafer et al. 2019, s.2; Doctor et al. 2022, s.12; Sheridan. E., 2023).

Aircraft developers are exploring battery electric aircraft as a promising avenue for zero emissions and cost-effective operations (Alfredsson et al. 2022). Battery electric aircraft could benefit from cheaper energy and reduced maintenance requirements. Electric propulsion offers flexibility in aircraft design and propulsion setups, potentially enabling more aerodynamically efficient aircraft through innovations like distributed propulsion (Friedrich & Robertson, 2015). This advancement could lead to highly efficient propulsion systems, revolutionizing the future of aviation (Alfredsson et al. 2022).

There exists an electric aircraft in the market known as the Velis Electro, developed by the Slovenian company Pipistrel, which received certification in 2020. However, it currently accommodates only two passengers (Pipistrel, 2023).

The Swedish company Heart Aerospace promises an electric airplane ES-30 with capacity of thirty passengers in operation around 2028. The range of fully electric aircraft should be around 200 kilometers (km), 400 km with electric- hybrid model (Heart Aerospace, 2023). Heart Aerospace also expects that the development of the battery technology in the late 2030's will push the range of the fully electric aircraft up to 400 km (Camelier, 2023).

In 2022, Embraer, Widerøe Zero & Rolls-Royce agreed to collaborate on a study of zero carbon aircraft concepts (Nowak, 2023). During the ZERAC-2023 conference, the ENERGIA FAMILY concept was introduced, comprising four aircraft models featuring various propulsion alternatives. With the evolution of the aviation sector in mind, the decision was made to concentrate on two specific models: one utilizing hybrid-electric propulsion and another powered by hydrogen fuel cells (Nowak, 2023).

Elfly Group from Norway produces an interesting concept, the all-electric seaplane. Model Noemi with an expected range of 315 km in 2040, introduces affordable, lightweight "floating airports," offering convenient entry to city harbors, coastal zones, and remote areas (Lithun, 2023).

While other companies are exploring theoretical concepts, Voltaero has already conducted tests on its hybrid prototype Cassio S. Intention is to enhance this model by introducing a 12-passenger variant (Botti, 2023).

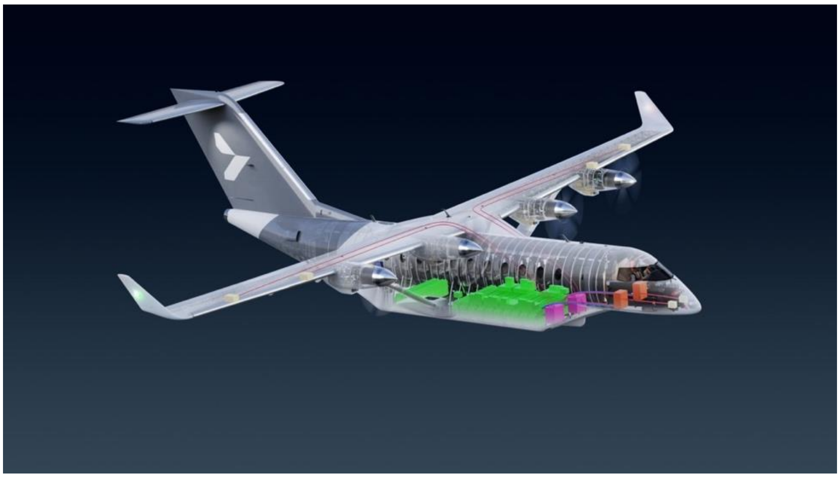

Figure 3: Heart Aerospace ES-30 – full electric model (Heart Aerospace, 2023).

2.3.2 Sustainable aviation fuel (SAF)

Decades ago, biofuels were introduced. They are used in pure form or blended with gasoline, diesel, or natural gas (DNV, 2023b). Biofuels are already extensively used in other segments of transport. The aviation is working towards sustainability by utilizing the sustainable aviation fuels (SAF). Long-haul flights produce the most emissions. Approximately 65% of the emissions reduction required for aviation to achieve net-zero by 2050 could potentially be attributed to the incorporation of SAF (IATA, 2022).

SAF can be produced using diverse methods, utilizing biological or non-biological components. Nevertheless, the production of large quantities of SAF from biological components presents a challenge in the sustainable acquisition of biological materials. The introduction of non-biological SAF production will therefore be crucial (DNV, 2023b).

SAF made their way into aviation but cost significantly more than fossil fuels. Currently, both airlines and passengers bear the additional costs. However, with the mandatory inclusion of SAF mandates is the price expected to drop. Consequently, the shift towards SAF is anticipated to be driven by regulatory requirements (DNV, 2023b).

Before compulsory blending mandates of SAF, has Norwegian aviation expressed intentions for increased share of sustainable biofuels by 2030 (AVINOR, 2020). Since 2007, AVINOR has been involved in SAF initiatives to reduce carbon emissions within the aviation sector. By January 2016, OSL Gardermoen achieved a significant milestone, as the first global hub to provide SAF to all refueling airlines (Reimers, 2018).

Regulations and certification programs for biological and non-biological SAFs came into existence 25th of April 2023, aligning with policies such as the European Green Deal and Fit for 55 (DNV, 2023b; CCU, 2023). The new regulation, ReFuelEU, aim to reduce carbon emissions in the aviation industry by mandating refuel suppliers to increase the blending of SAF from 2025 (DNV, 2023b). The SAF mandate will start at 2% in 2025 and gradually increase to 70% in 2050 (Figure 4).

AVINOR collaborates with Bio4Fuels, an FME (Centre for Environment-friendly Energy Research) based at the Norwegian University of Life Sciences led by SINTEF. AVINOR additionally engages in various research and development initiatives focused on SAF (AVINOR, 2022).

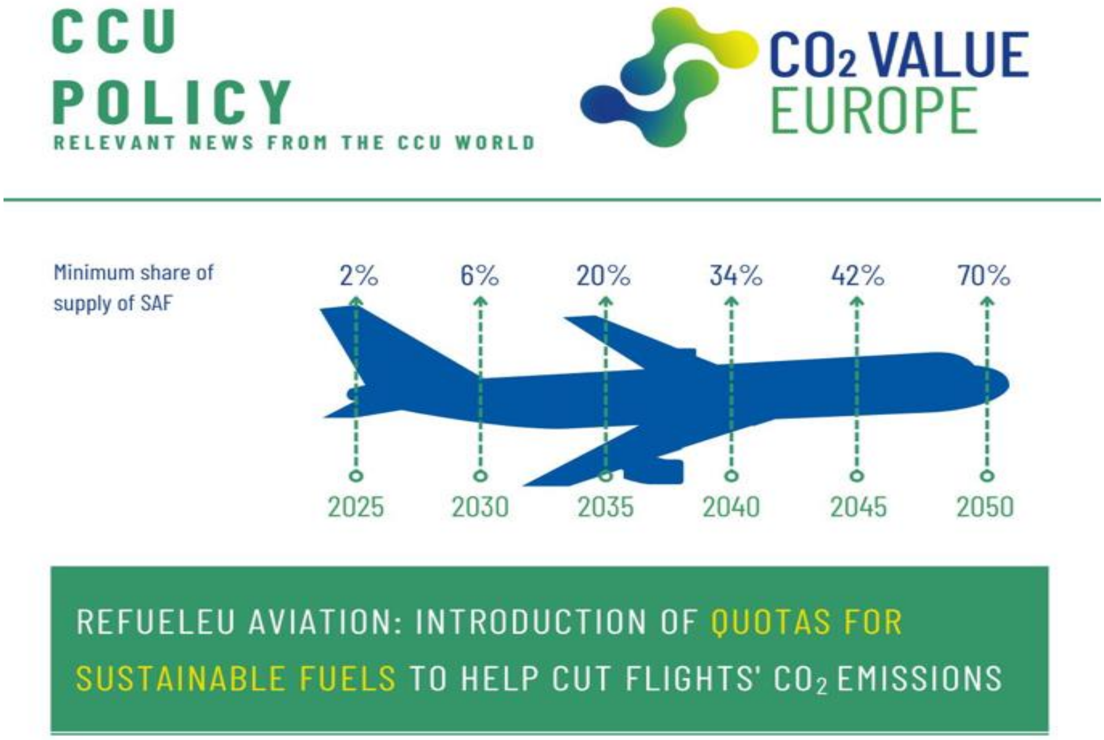

Figure 4: quotas for minimum share of supply of SAF (CCU, 2023).

2.3.3 Hydrogen

Hydrogen is acknowledged as a crucial energy carrier in reducing carbon emissions in transport. European Union have implemented strategies and goals in its EU Hydrogen Strategy, where the aim is to annually produce 10 million tonnes of renewable hydrogen and install 40 GW of electrolysers by 2030 (DNV, 2022).

EU member states, such as Germany, Sweden, and Denmark, have recently introduced their own hydrogen strategies. Norway has focus on advancing hydrogen technology through research and policy development (DNV, 2022). The application of hydrogen in aviation is still a relatively recent development, yet it is recognized as a feasible choice for enhancing the sectors environmental sustainability. Norway is one of the countries that have good conditions for the development of hydrogen production, thanks to a large share of renewable energy.

Norway has number of small regional airports that are ideal for integrating hydrogen. However, the implementation of hydrogen in aviation also presents challenges associated with the supply chain at the larger airports (Figure 5). The most favorable choice involves generating hydrogen close to the airport. However, due to the location of most airports, this option is not feasible. Hence, transporting hydrogen from external sites becomes a more feasible solution (Figure 5).

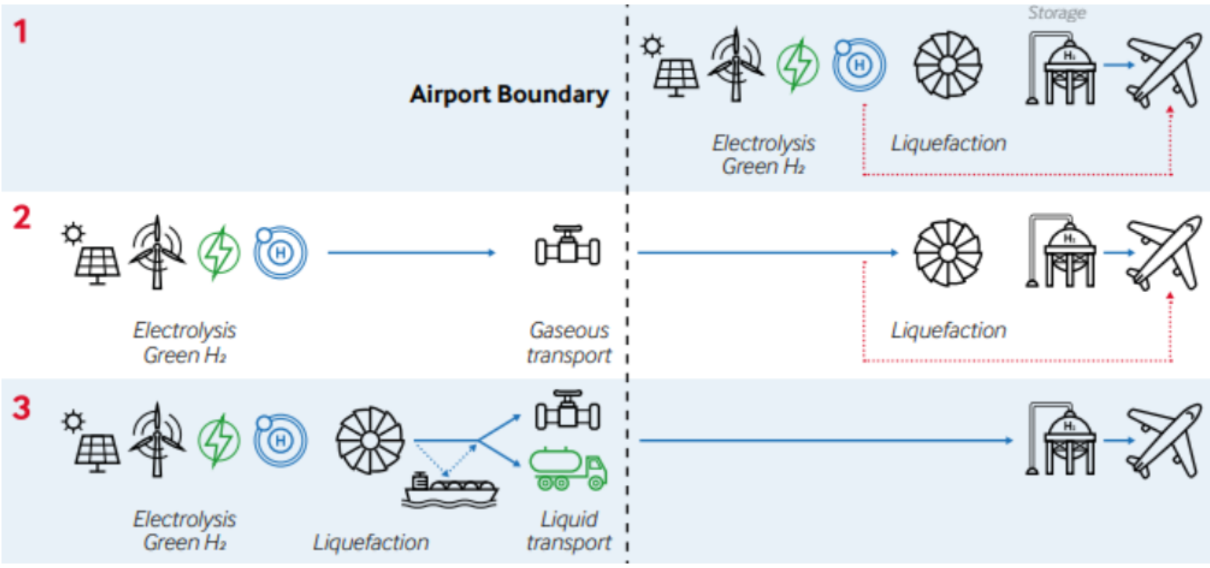

Figure 5: Hydrogen supply chain options to the airport (DNV, 2022).

3.0 Case description

This chapter describes the case study of OSL Gardermoen. The first paragraph provides a general information about OSL Gardermoen, while the second paragraph documents the specific energy use at the airport.

3.1 Oslo Airport Gardermoen

Norway's largest airport, OSL Gardermoen, is an international airport situated on the border between Nannestad and Ullensaker municipalities in Viken, forty kilometers north of Oslo. OSL Gardermoen is managed by the government's airport operator AVINOR, with twenty-eight million passengers passing through the airport annually (Wikipedia, 2023b). It has two parallel runways and seventy-one stands, which are mostly used by Norwegian, SAS and Widerøe airlines (Wikipedia, 2023b). Energy consumption varies from year to year depending on the weather, and the number of passengers.

Figure 6: Location of Oslo Gardermoen (Google Maps, 2023).

3.2 Current energy use

The Energinet documents the energy consumption of OSL Gardermoen. Energinet is an energy monitoring system for energy and environmental reporting. The total electricity consumption for 2022 was around 121 GWh (Figure 9), while district heating powered by electricity made around 22 GWh (Energinet, 2023). The energy consumption for electricity and district heating is contingent upon outside temperatures, as illustrated in Figures 7 and 8.

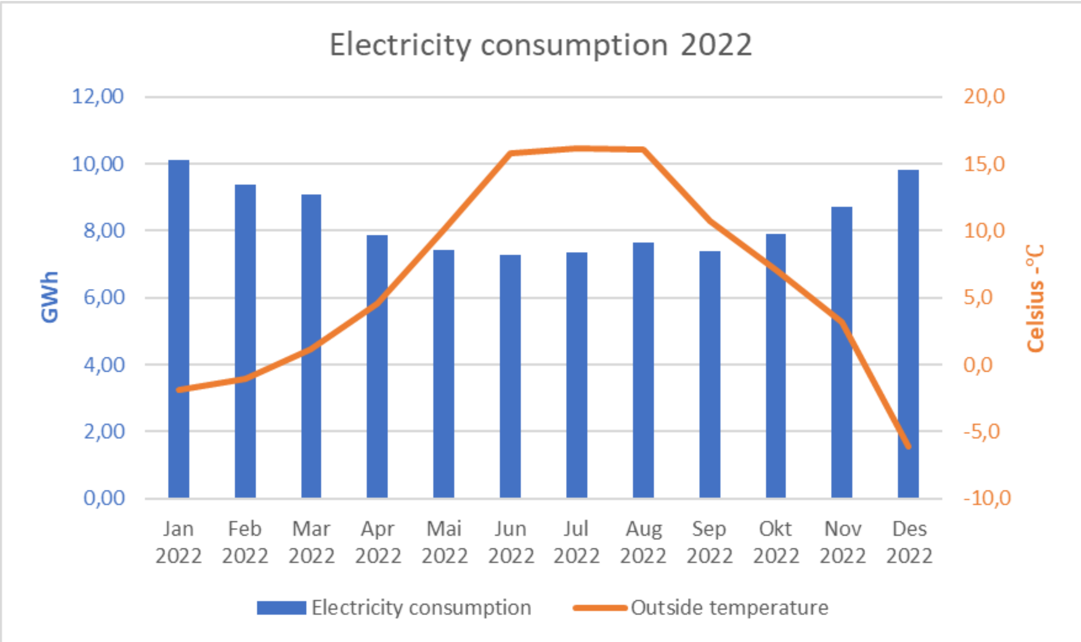

Figure 7:Electricity consumption over the year 2022 (Energinet, 2023).

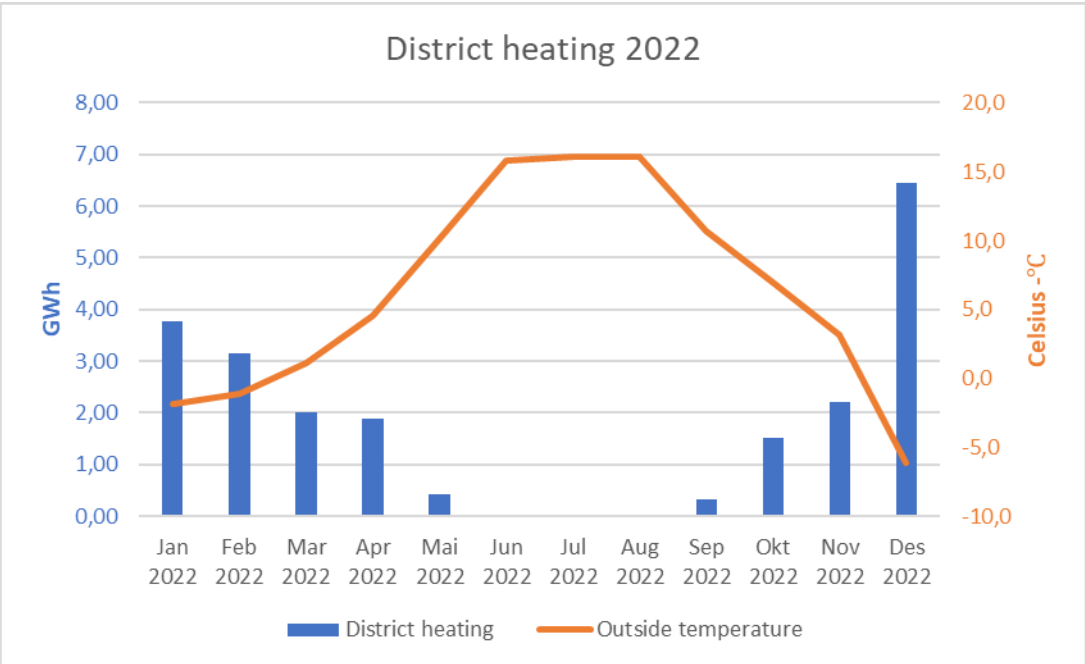

Figure 8:District heating over the year 2022 (Energinet, 2023

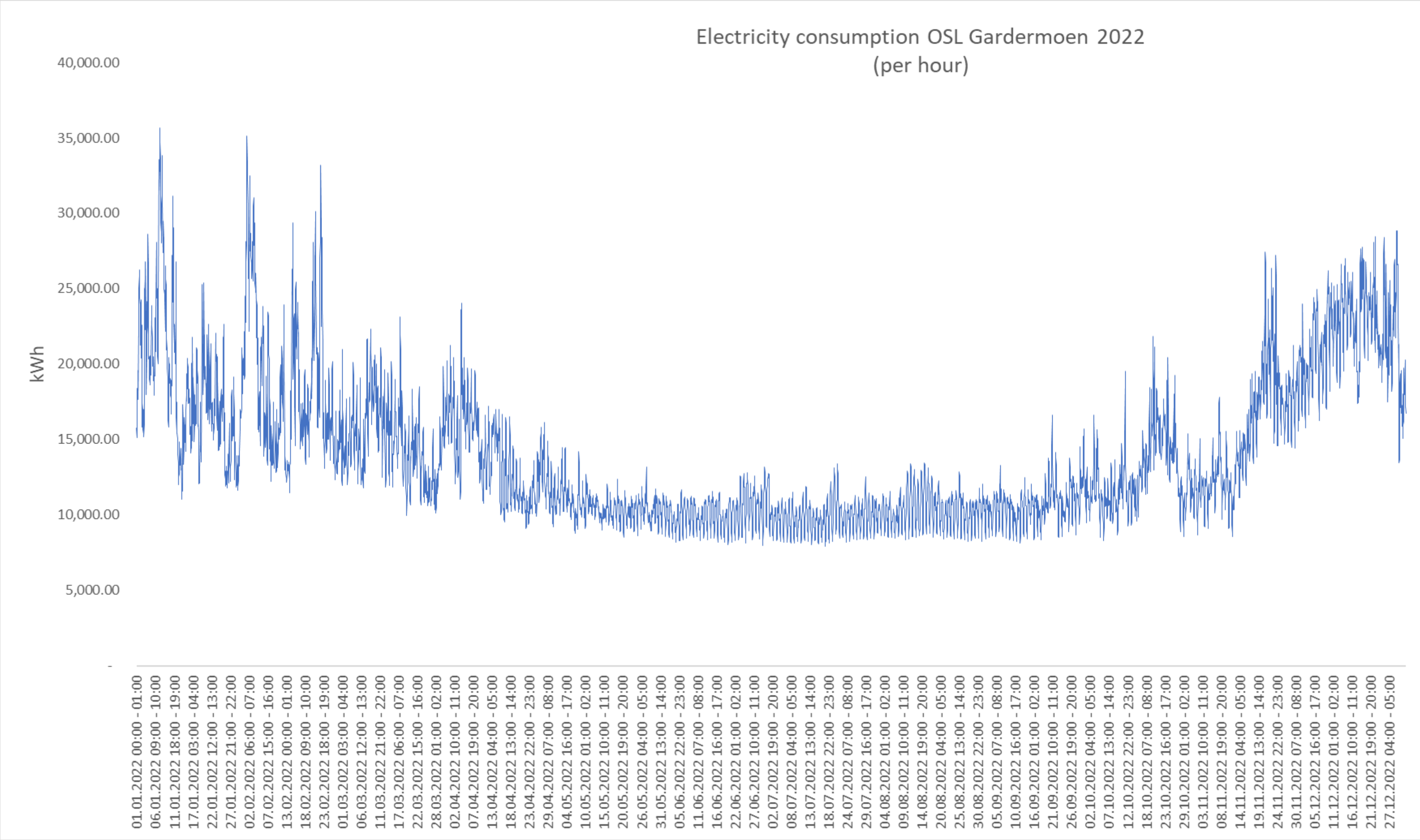

Figure 9: Hourly electricity consumption of OSL Gardermoen, per year 2022.

Fossil fuels such as diesel and gasoline are still widely used, despite ongoing electrification. Aviation fuel Jet A1 accounts for the highest fossil fuel consumption, 70,4 million liters in 2022. The consumption of diesel and gasoline for ground handling, reserve power, own vehicles, and winter maintenance equals to 990 857 liters per year. For more detailed fossil fuel consumption for ground handling refer to APENDIX A.

Table 1: Fossil fuel consumption by category, OSL Gardermoen 2022 (A. Rognan, personal communication, 1.12.2023).

FOSSIL FUEL CONSUMPTION 2022			
Aviation fuel *	Jet A1	70 415 000	liter
Own vehicles			
	Gasoline	11 169	liter
	Diesel	1 784	liter
Thermal energy (other facilities)			
Reserve power/ track station	Diesel	25 684	liter
Winter maintanance (flyght side)			
	Diesel	2 015	liter
Ground handling			
	Gasoline	19 238	liter
	Diesel	930 967	liter

**This value contains only the air traffic LTO cycle for Scope 3 emission report (A. Rognan, personal communication, 1.12.2023).*

The significant change in terms of fossil fuel consumption occurred in ground handling, where large part of small vehicles was electrified, and shuttle busses started to use biodiesel. Large service machines such as snowplows, de-icing machines and fire trucks are the challenge, and it will not be possible to electrify all AVINOR's heavy vehicles within 2030. As indicated in Table 2, the uptake of advanced biodiesel is completely necessary. In 2022, 43% of all diesel consumption at AVINOR's airports was advanced biodiesel (AVINOR, 2022).

Table 2:Biofuel consumption, OSL Gardermoen 2022 (A. Rognan, personal communication, 1.12.2023).

BIOFUEL CONSUMPTION 2022		
Own vehicles		
Biodiesel, 2GPolar	636 885	liter
Thermal energy (energisentral)		
Biofuel oil (HVO100)	50 590	liter
Thermal energy (other facilities)		
Biofuel oil (HVO)	57 406	liter
Winter maintanance (flight side)		
Biodiesel, 2GPolar	38 520	liter
Ground operations - bussing		
Biodiesel, 2GPolar	25 984	liter

As noted previously, large part of the small ground handling vehicles has been electrified. In 2022, the electricity consumption for charging electric ground handling vehicles was 148 704 kWh. The Figure 10 illustrates the charging pattern of electric ground handling vehicles throughout the week - Monday to Sunday. As flights occur predominantly during the day, most charging activities take place between 10 PM and 5 AM. These charging data uses in the modeling of electricity demand in Scenario 1- net-zero airport.

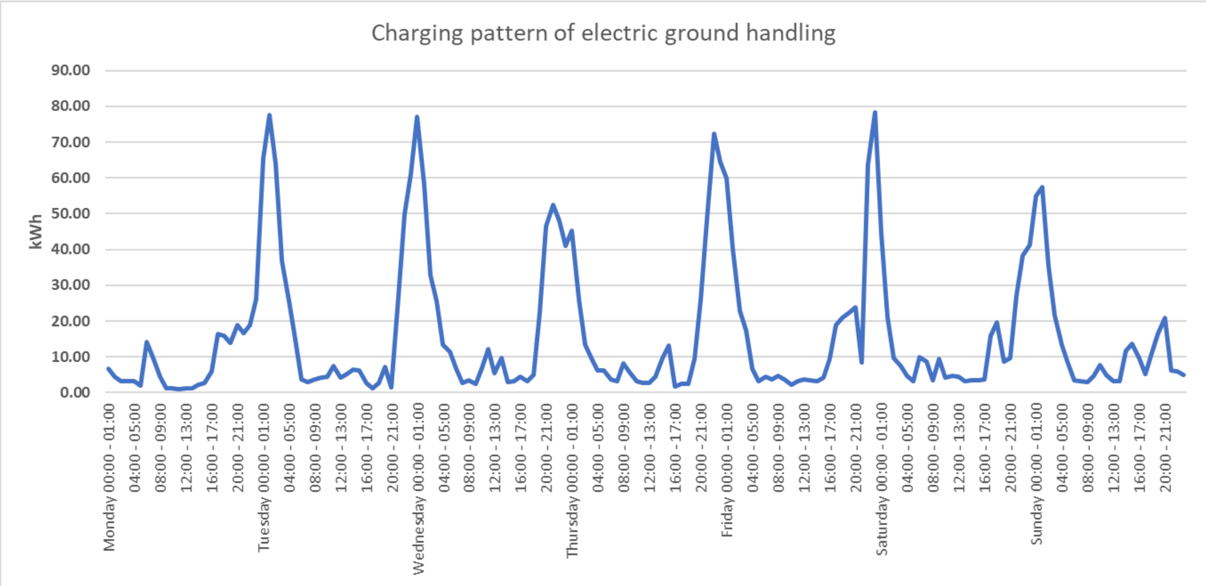

Figure 10: Charging pattern of ground handling (kWh), (Energinet, 2023).

4.0 Method

The case study of OSL Gardermoen model electricity demand of a zero-emission airport with focus on three different scenarios. This chapter covers fundamental steps applicable for all three scenarios, namely:

- collection of the data from Energinet, internal reports of AVINOR
- analysis of the data
- conversion of fossil fuel consumption to kWh – ground handling
- modeling the charging pattern for electrified fossil fuel ground handling
- modeling the charging pattern of electric and hybrid aircraft (Chapter 5-Scenarios)
- modeling the future electricity demand for OSL Gardermoen (Chapter 5-Scenarios)

For more detailed data and procedures for each scenario refer to Chapter 5 - Scenarios.

4.1 Collection and analysis of data

We use real-time data from Energinet and internal reports of AVINOR. In Energinet, the energy consumption categorizes into separate groups such as delivered energy, energy consumption of external companies and charging of electric vehicles. We concentrated on data for delivered energy for the entire OSL Gardermoen.

Corona virus affected the international and national air transport in the last years. Therefore, we excluded the data from 2020 and 2021. Another aspect of using 2022 data pertains the electrification of ground handling. Before 2022, Menzies was the only company operating electric ground handling vehicles, however since then, three additional companies have become involved. Hence, the data from 2022 provides more comprehensive understanding of the overall electricity consumption and ground handling electricity consumption. The 2022 data for every hour was downloaded to Excel and reviewed in RStudio to identify any incorrect values. Zero values occurred at few hours throughout the year. After the occurrence of these zero values, consistently appeared high values of electricity consumption. Following the personal discussion with Wiggo Roar Dehli, who oversees Energinet, we determined that these zero values stem from a system malfunction. The high values were pinpointed as a consolidation of past electricity consumption. We evenly distributed the consolidation of past electricity consumption across the zero values. The same procedure applies to the ground handling charging data from 2022. The analyzed data uses in the modeling of electricity demand of OSL Gardermoen in all three scenarios.

4.2 Conversion of fossil fuel consumption to kWh – ground handling

I obtained data from AVINOR`s internal reports regarding the consumption of fossil fuels for ground handling, reserve power and winter maintenance. The focus was on the fossil fuel consumption of ground handling and AVINOR's vehicles since winter maintenance and reserve power expects to shift from fossil fuels to biodiesel due to technological challenges.
This step determines the annual electricity requirement for electrifying fossil fuel ground handling and own vehicles. The fossil fuel consumption for ground handling and own vehicles measures in liters. To optimize the data handling, the consumption in liters was converted into kWh using the following factors:

$$1\ liter\ of\ gasoline = 9{,}1\ kWh\ (SEAI, 2023)$$

$$1\ liter\ of\ diesel = 10{,}1\ kWh\ (SEAI, 2023)$$

Table 3:Fossil fuel consumption in liters converted to kWh (H. Ringnes, personal communication 26.9.2023).

FOSSIL FUELS 2022						
Category		**Consumption**		**Factor**	**Energy**	
Own vehicles						
	Gasoline	11 169	liter	9,1	101 638	kWh
	Diesel	1 784	liter	10,1	18 018	kWh
Ground handling						
	Gasoline	19 238	liter	9,1	175 066	kWh
	Diesel	930 967	liter	10,1	9 402 767	kWh
SUM						
	Gasoline				276 704	kWh
	Diesel				9 420 785	kWh

It is crucial to consider the efficiency of combustion engines versus electric engine, when converting fossil fuel consumption in liters to kWh. A typical gasoline engine operates roughly at 25% efficiency, whereas a diesel engine operates at 40% efficiency (Wikipedia, 2023c). Compared to the combustion engines, the electric engine is significantly more efficient, around 85% (NRDC, 2019). We calculated the "output" energy of each fossil fuel in kWh based on the efficiency of the combustion engines (Equation 1).

Equation 1

$$Energy\ output = Energy\ input * engine\ efficiency$$

In the last step, we determined the “input” energy for the electric motor by dividing the “output” energy with efficiency of electric motor (Equation 2).

Equation 2

$$Energy\ input = \frac{Energy\ output}{engine\ efficiency}$$

The yearly ground handling fossil fuel consumption of 963 158 litres is equivalent to 4 514 694 kWh yearly for charging electrified ground handling vehicles (Table4).

Table 4: Energy output based on efficiency; ground handling electrified.

Fossil Fuel Ground handling	Energy input		Engine efficiency	Energy output	
Gasoline	276 704	kWh	0,25	69 176	kWh
Diesel	9 420 785	kWh	0,4	3 768 314	kWh
SUM				**3 837 490**	**kWh**
Electrified Ground handling	**4 514 694**	**kWh**	**0,85**	**3 837 490**	**kWh**

4.3 Modeling the charging pattern for electrified fossil fuel ground handling.

As outlined in section 3.2, majority of the charging of electric ground handling vehicles takes place between 10 PM and 5 AM. Given that electrified fossil fuel ground handling vehicles are anticipated to follow a similar charging schedule, we allocated the electricity consumption to conform with charging pattern of existing electric ground handling.

The yearly 4 514 694 kWh consumption represents in Equation 3 the energy input of electrified fossil fuel ground handling (FF EL). To replicate the charging pattern of existing electric ground handling, I applied the Equation 3 to each hour of electrified fossil fuel ground handling. The final values are referenced in the text as "ground handling fossil fuel electrified."

Equation 3

$$\left(\frac{hourly\ el.consumption\ of\ electric\ ground\ handling}{total\ el.consumption\ of\ electric\ ground\ handling}\right) * energy\ input\ FF\ EL$$

5.0 Scenarios

This chapter elaborates on and document three different scenarios:

- Scenario I – electric airplanes
- Scenario II – hybrid airplanes = electric + SAF
- Scenario III – Hydrogen airplanes

5.1 Scenario I

Scenario I concentrate on the concept of net-zero airport. The concept of net-zero airport involves electric domestic transport, as well as electrified fossil fuel ground handling, and transition of heavy vehicles from fossil fuels to biodiesel.

The first step involves choosing the electric aircraft intended for use in this scenario. I attended the ZERAC-2023 conference in Oslo, where multiple electric aircraft models were presented. I chose the electric model ES-30 from Heart Aerospace based on literature review, personal interviews conducted at the conference, and the recommendation of Erik By- manager for energy transition program at AVINOR (Alfredson et al., 2022, s.9, AVINOR, personal communication 16.11.2023).

The electric aircraft ES-30 should have range around 400km in late 2030's, with the maximum cruising speed of 350 km/hour and 30 passengers' seats (Camelier, 2023; AVIATION WEEK NETWORK, 2023). The assumed capacity of the battery is 1 MW (Alfredsson et al., 2022; E. By, personal communication 16.11.2023).

The four flight routes from OSL Gardermoen were selected for this scenario due to their popularity and required distance of up to 400 km:

Table 5: Four selected routes from OSL Gardermoen.

FROM	TO	DISTANCE
OSL Gardermoen	Kristiansand	285 km
OSL Gardermoen	Bergen	324 km
OSL Gardermoen	Stavanger	340 km
OSL Gardermoen	Trondheim	363 km

5.1.1 Factors

The modelling of electric flight as a replacement for fossil fuel-powered flight requires consideration of several factors:

- Aircraft type
- Seat capacity
- Load factor
- Maximum cruising speed

SAS and Norwegian are currently the airlines operating on these four routes. The aircraft fleet consists of AIRBUS A320 and BOEING 737 (AVINOR, 2023). AIRBUS A320 has maximum cruising speed of 850 km/hour with capacity of 168 seats, while BOEING 737 has maximum cruising speed of 850 km/hour with capacity of 186 seats. SAS flights maintain a load factor of 78,2 %, whereas flights of Norwegian airlines achieve a load factor of 87,4 % (SAS, 2023; Norwegian, 2023). To standardize the data for one route, the average of actual passengers flying was calculated.

Table 6: The average number of passengers flying on one route (SAS, 2023; Norwegian, 2023).

Aeroline	Aircafts seat capacity	Load factor	Actual number of passengers
Norwegian	168	87,40 %	147
SAS	186	78,20 %	145
Average	**177**	**82,80 %**	**147**

If we consider the ES-30 electric plane with the seating capacity of 30 passengers with 100% load factor, it is necessary to operate five separate electric flights to accommodate the equivalent number of average actual flying passengers.

The maximum cruising speed is another factor to consider. Since electric aircraft have maximum cruising speed that is less than half of fossil fuel-powered aircraft, it is necessary to determine whether the flight time will significantly change. The AVINOR official flight schedule indicates that each of the four flights has a duration of 55 minutes (AVINOR, 2023). We utilized the Flightradar application for each flight to determine the actual flight duration by tracking the aircraft’s speed. The speed of the aircraft (v) was logged every minute (t) to generate a flight record. The subsequent step involved calculation of electric flight duration with maximum cruising speed of 350 km/hour. Equation 7 was applied to each minute of the real flight data of fossil fuel-powered flights, to calculate the duration of electric flight.

Equation 7

$$Area = \frac{(v_1+v_2)}{2*(t_2-t_1)}$$

The electric flight to Kristiansand lasts 25 minutes longer, while flight to Trondheim lasts 30 minutes longer, compared to fossil fuel-powered real flight. The electric flight to Kristiansand is 12 longer than the official flight duration, while for Trondheim the increase is 17 minutes (Figure 11, Figure 12).

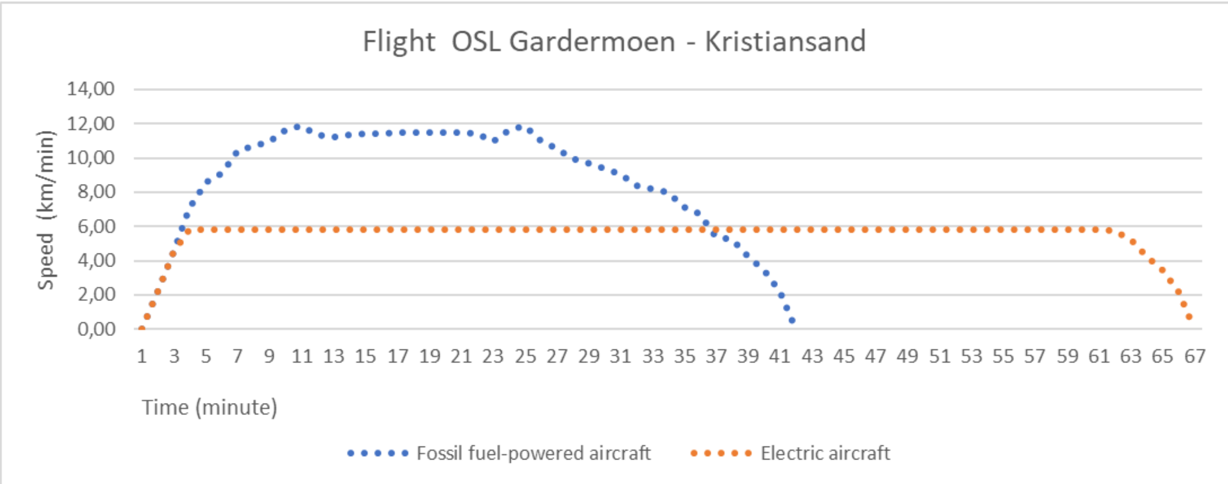

Figure 11: Flight OSL Gardermoen - Kristiansand, electric aircraft vs fossil fuel-powered aircraft.

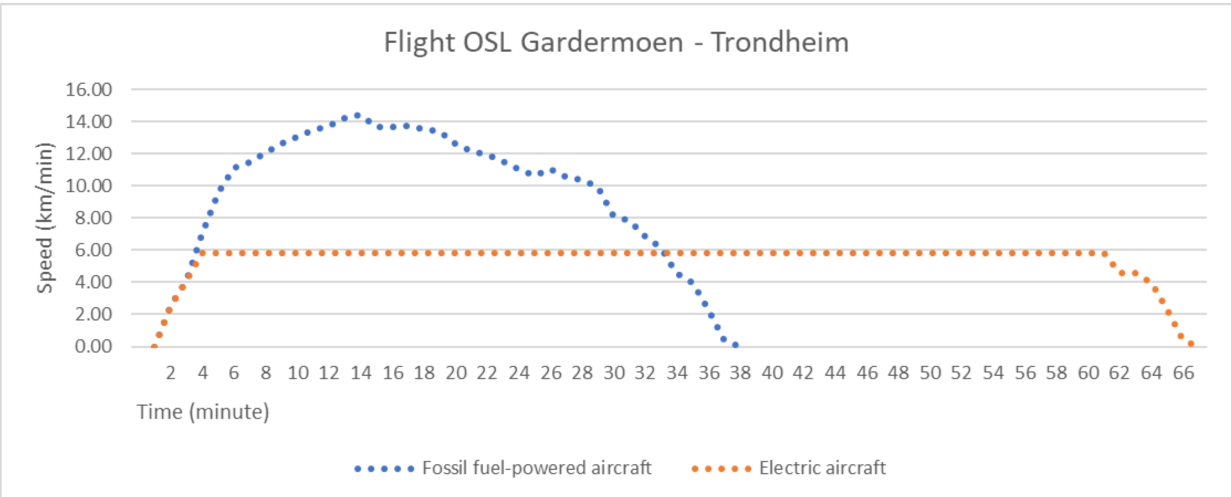

Figure 12: Flight OSL Gardermoen - Trondheim, electric aircraft vs fossil fuel-powered aircraft.

The electric flight to Stavanger lasts 27 minutes longer compared to fossil fuel-powered real flight and is 12 minutes longer than the official flight duration (Figure 13).

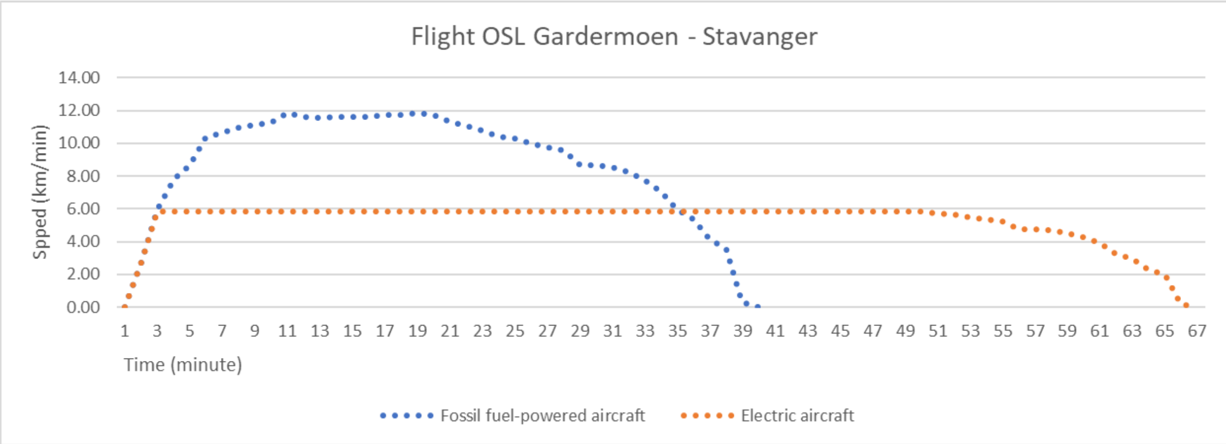

Figure 13: Flight OSL Gardermoen - Stavanger, electric aircraft vs fossil fuel-powered aircraft.

The flight to Bergen has the significant increase, as the time of the electric flight doubles compared to fossil fuel-powered flight. The real flight time compared to official flight duration has increased by 47 minutes (Figure 14).

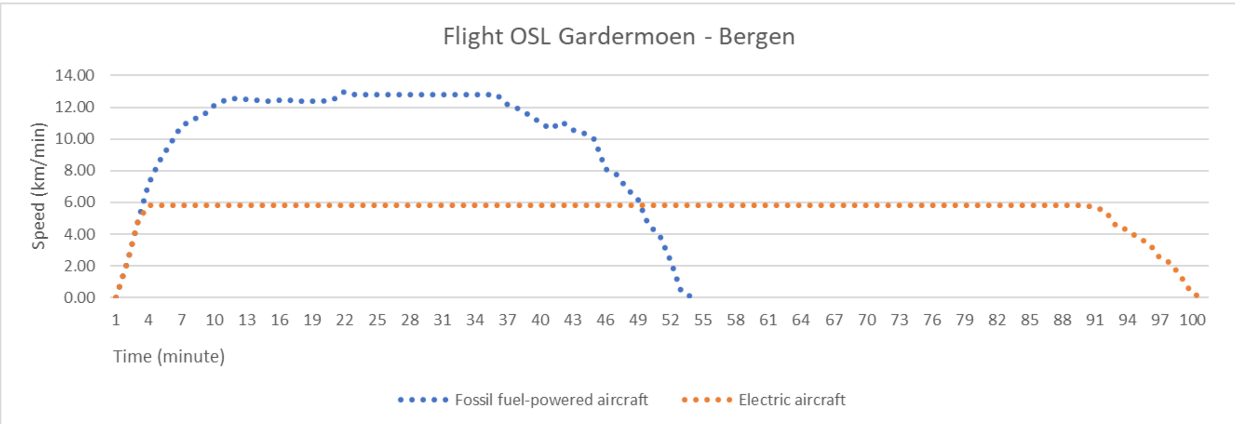

Figure 14: Flight OSL Gardermoen - Bergen, electric aircraft vs fossil fuel-powered aircraft.

5.1.2 Flight schedule and charging pattern.

Flight schedule for these four routes is required to model the charging pattern of electric aircrafts. The flight schedule of departures from OSL Gardermoen was determined by calculating the daily average of flights for each day over the month and combining departure time in existing flight schedule (refer to appendix B). To account for the actual number of passengers flying, it is necessary to multiply the average number of flights by five. However, the doubled duration of electric flight to Bergen, has resulted in additional flight per route to meet the daily passenger demand. This caused 1000% increase in flights on route OSL Gardermoen – Bergen (Table 8).

Table 7: Average number of flights for each route (AVINOR, 2023).

AVERAGE NUMBER OF FLIGHTS				
	STAVANGER	BERGEN	KRISTIANSAND	TRONDHEIM
Monday	15	17	4	16
Tuesday	17	18	5	16
Wednesday	17	18	6	20
Thursday	18	19	5	20
Friday	16	18	6	22
Saturday	7	7	0	8
Sunday	15	18	4	20

Table 8: Average number of flights for each route to account for the actual number of passengers flying.

AVERAGE NUMBER OF FLIGHTS - DAILY PASSENGER DEMAND				
	STAVANGER	BERGEN	KRISTIANSAND	TRONDHEIM
Monday	75	170	20	80
Tuesday	85	180	25	80
Wednesday	85	180	30	100
Thursday	90	190	25	100
Friday	80	180	30	110
Saturday	35	70	0	40
Sunday	75	180	20	100

We used the data of monthly average departures from OSL Gardermoen, the duration of electric flights, flying schedule and number of flights needed to accommodate the actual number of passengers flying, to model the charging pattern of electric aircrafts and total electricity demand of OSL Gardermoen (AVINOR, 2023; Flightradar, 2023; SAS, 2023; Norwegian, 2023).

5.2 Scenario II

Scenario II highlights the utilization of ES-30 hybrid model with reduced capacity of 25 passengers and maximum cruising speed of 350km/hour with increased flight range up to 800km (Camelier, 2023). The hybrid model employs electricity during take-off, landing, and cruising, whereas we assume that SAF, as a hybrid solution, is utilized solely during the cruising phase of the flight.

We selected the flight from OSL Gardermoen to Bodø for this scenario based on the distance. We utilized the Flightradar application also for this flight, to determine the actual flight duration by tracking the aircraft's speed. The speed of the aircraft (v) was logged every minute (t) to generate a flight record. We applied the Equation 7 from Scenario I to each minute of the real flight data of fossil fuel-powered flights, to calculate the duration of electric flight.

The electric flight to Bodø is 66 minutes longer compared to the fossil fuel-powered real flight. The real flight time compared to official flight duration has increased by 47 minutes (Figure 15).

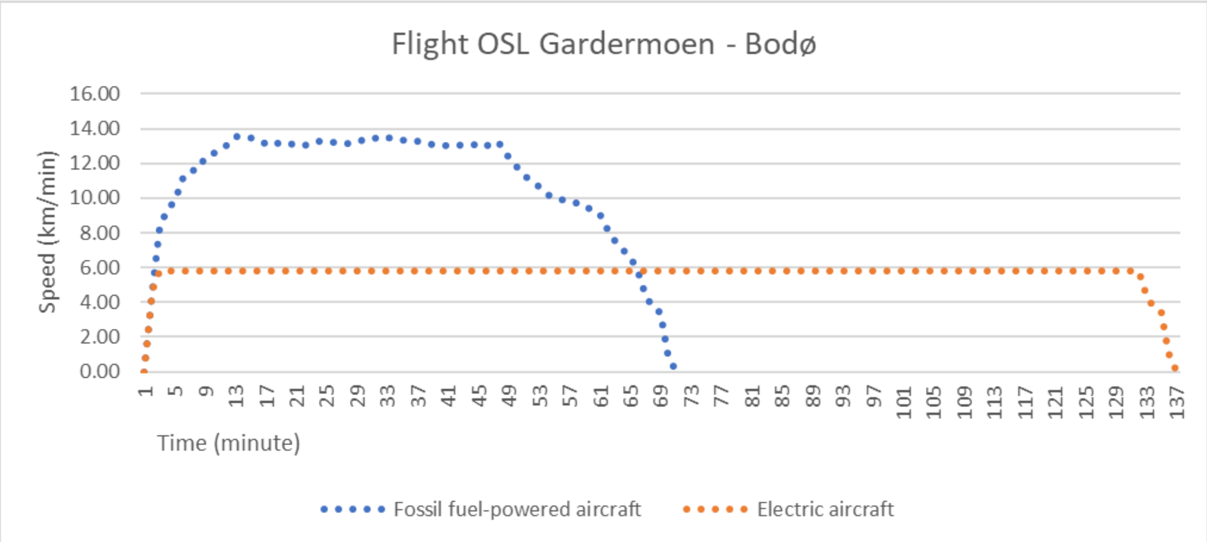

Figure 15: Flight OSL Gardermoen - Bodø, electric aircraft vs fossil fuel/powered aircraft.

The flight schedule for this hybrid flight encompasses identical data to Scenario I, except the number of passengers seats for ES-30. If we consider the ES-30 hybrid aircraft with a seating capacity of 25 passengers with 100% load factor, it is necessary to operate six separate flights, to accommodate the equivalent number of average actual flying passengers. The doubled duration of electric flight to Bodø has resulted in additional flight per route to meet the daily passenger demand. This caused 600% increase in flights on route OSL Gardermoen – Bodø (Table 9).

Table 9: Average number of flights, OSL Gardermoen - Bodø.

AVERAGE NUMBER OF FLIGHTS		INCREASED NUMBER OF AVERAGE FLIGHTS	
	BODØ		BODØ
Monday	5	Monday	30
Tuesday	7	Tuesday	42
Wednesday	8	Wednesday	48
Thursday	7	Thursday	42
Friday	7	Friday	42
Saturday	2	Saturday	12
Sunday	4	Sunday	24

We used the data of monthly average departures from OSL Gardermoen, the duration of electric flight, flying schedule and number of flights needed to accommodate the actual number of passengers flying, to model the charging pattern of hybrid aircraft and total electricity demand of OSL Gardermoen (AVINOR, 2023; Flightradar, 2023; SAS, 2023; Norwegian, 2023).

5.3 Scenario III

Scenario III focuses on hydrogen planes, which are together with SAF the expected replacement for long-haul fossil fuel-powered flights. We assume that hydrogen aircraft uses electricity during takeoff and landing and utilizes hydrogen during the cruising phase of the flight. In this scenario was used a simplified calculation due to the lack of technical parameters of hydrogen aircraft.

First, we calculated the average number of passenger seats per international flight, based on the most frequently used aircrafts for international flights from OSL Gardermoen. The amount of electricity used per passenger in an electric airplane ES-30 was calculated and multiplied by average number of passenger seats per international flight.

Table 10: Average number of passengers per international flight.

Aircraft	Number of passengers seats
Airbus A350	350
Boeing 747-400	524
Airbus A340-300	267
Airbus A340-600	475
Boeing 737 MAX8	189
AVERAGE	**361**

Table 11: Electricity consumption per passenger/ international flight.

Aircraft	NO. Passengers	El.Consumption		El.use /passenger	
Electric aircraft ES-30	30	1	MWh	0,03	MWh
International flight - average	361	12,03	MWh	0,03	MWh

The average number of international flights departing from OSL Gardermoen per day throughout the month was calculated and used for final calculation of electricity consumption per day (Equation 8; APPENDIX C).

Equation 8

$$El.comsuption\ per\ day = El.consumption\ per\ flight * number\ of\ flights\ per\ day.$$

6.0 Results

This chapter presents the results for each scenario, encompassing the total future electricity demand of OSL Gardermoen. Scenario I, which focuses on net-zero airport concept, doubled the electricity demand. In Scenario II, the inclusion of a single route of hybrid aircraft marked additional 30 % increase in electricity demand. Scenario III presents an extreme outcome where implementation of hydrogen airplanes resulted in 459% increase of electricity demand.

6.2 Scenario I

Scenario I with the net-zero airport concept includes electrified fossil fuel ground handling which accounted for 4,51 GWh per year. The Figure 16 illustrates the modelled charging pattern of the electrified fossil fuel ground handling throughout the week based on charging pattern of existing electric ground handling.

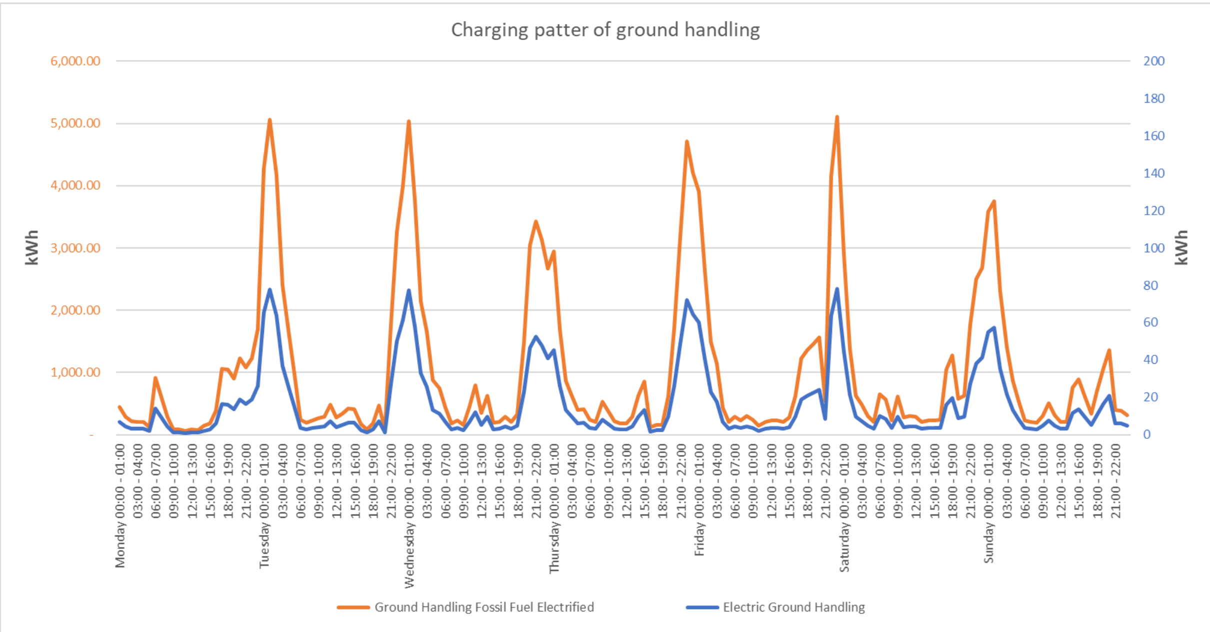

Figure 16: Charging pattern of electric ground handling & ground handling fossil fuel electrified.

The noteworthy result was the charging pattern of the four electrified domestic flights (Stavanger, Bergen, Kristiansand, Trondheim), where the total electricity consumption for charging electric aircrafts was 132 GWh per year, which resulted together with electrified ground handling in an annual increase of electricity consumption at OSL Gardermoen by 112% (Figure 17, Figure 18, Figure 19).

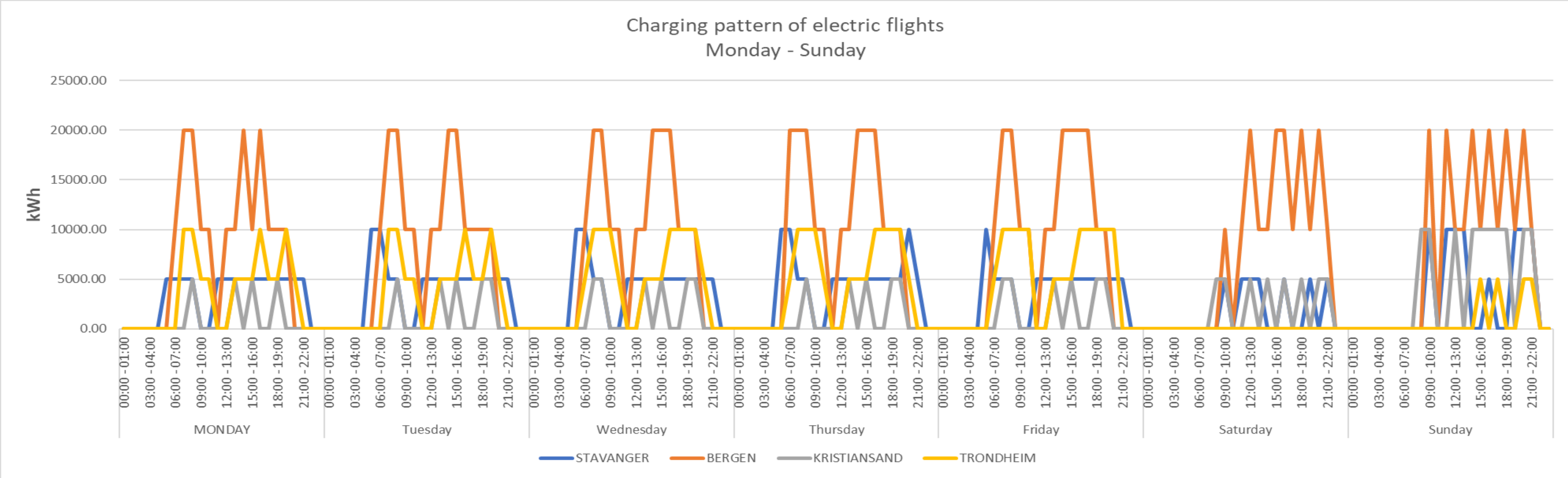

Figure 17: Charging pattern of all domestic electric flight throughout the week.

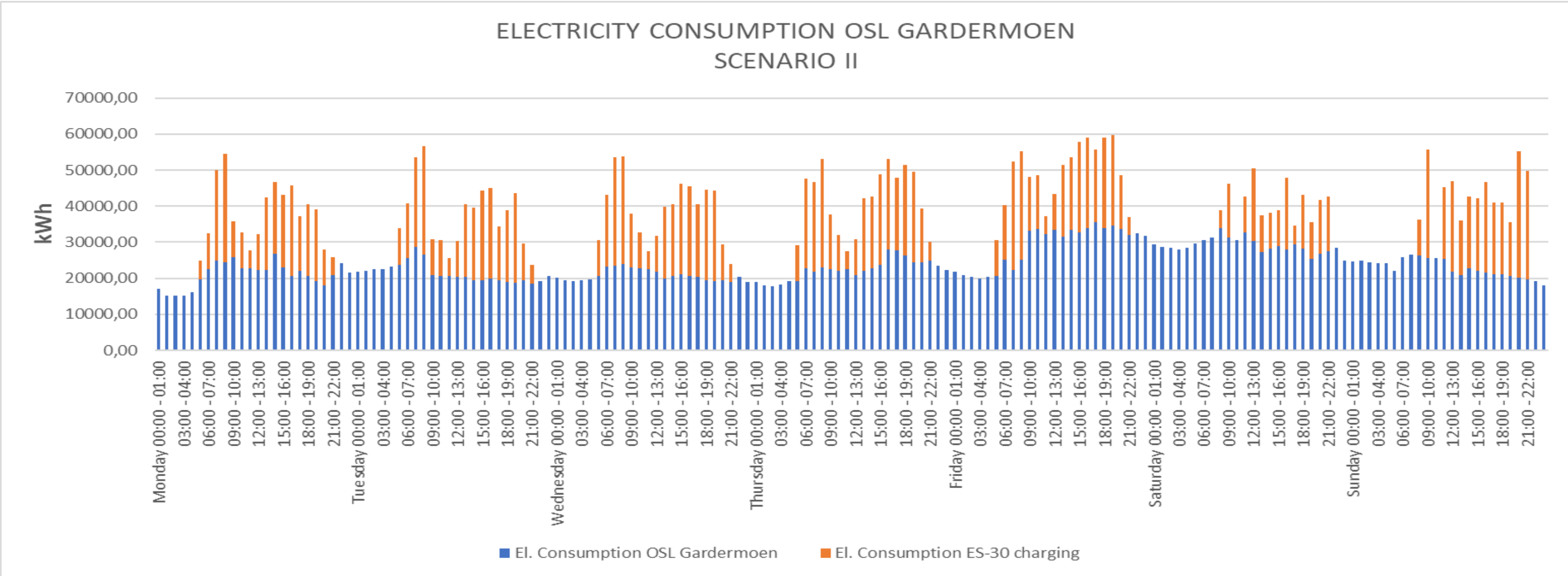

Figure 18:Charging patter ES-30, Monday - Sunday, Scenario I.

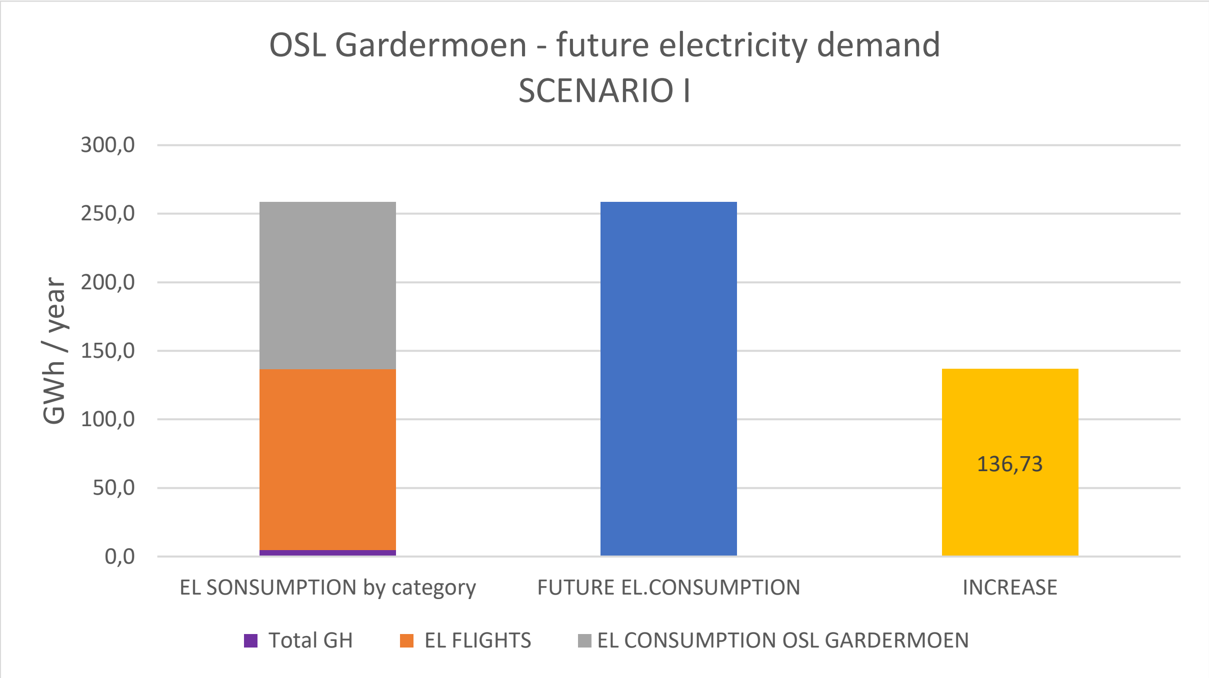

Figure 19: OSL Gardermoen - future electricity demand, Scenario I.

The peak-to-average ratio for electricity demand throughout the year shows the highest values in two months - August and October (Table 12). The final costs of electricity consumption depend on three factors: fixed tariff, energy tariff and power tariff. The peak-to-average ratio has a direct impact on the power tariff, since the price calculates based on the highest monthly power demand. The peaks in August and October can be moved to less demanding hours to reduce overall electricity costs. The vehicle-to-grid charging energy system (V2G) may offer a solution in the future.

On the contrary, the lowest value occurred in the month of December, where the total electricity consumption of OSL Gardermoen is impacted by low outside temperatures and high electricity consumption of district heating.

Table 12: Peak-to-average ratio of electricity consumption throughout the year 2022, Scenario I.

JANUARY			JULY		
Average demand	30322,32	kWh	Average demand	21691,52	kWh
Peak	59905,74	kWh	Peak	45113,73	kWh
Peak-to-average ratio	1,98		Peak-to-average ratio	2,08	
FEBRUARY			**AUGUST**		
Average demand	30443,36	kWh	Average demand	22200,26	kWh
Peak	63418,53	kWh	Peak	47525,37	kWh
Peak-to-average ratio	2,08		Peak-to-average ratio	2,14	
MARCH			**SEPTEMBER**		
Average demand	26829,92	kWh	Average demand	22615,27	kWh
Peak	52406,60	kWh	Peak	46684,86	kWh
Peak-to-average ratio	1,95		Peak-to-average ratio	2,06	
APRIL			**OCTOBER**		
Average demand	25336,75	kWh	Average demand	24363,09	kWh
Peak	53802,81	kWh	Peak	52032,59	kWh
Peak-to-average ratio	2,12		Peak-to-average ratio	2,14	
MAY			**NOVEMBER**		
Average demand	22397,15	kWh	Average demand	27106,15	kWh
Peak	45445,12	kWh	Peak	56447,67	kWh
Peak-to-average ratio	2,03		Peak-to-average ratio	2,08	
JUNE			**DECEMBER**		
Average demand	22110,08	kWh	Average demand	34248,2	kWh
Peak	46209,74	kWh	Peak	62449,8	kWh
Peak-to-average ratio	2,09		Peak-to-average ratio	1,82	

6.2 Scenario II

The result from Scenario II illustrates the outcome of charging the single hybrid aircraft on route OSL Gardermoen – Bodø. The yearly electricity demand with charging ES-30 increases by 21,56 GWh. When this hybrid flight is added to Scenario I, the annual electricity demand for OSL Gardermoen increases by 158.29 GWh/year, which represents increase of 130% compared to actual electricity consumption (Figure 21). Figure 20 shows that charging a single hybrid aircraft changes the peaks throughout the week.

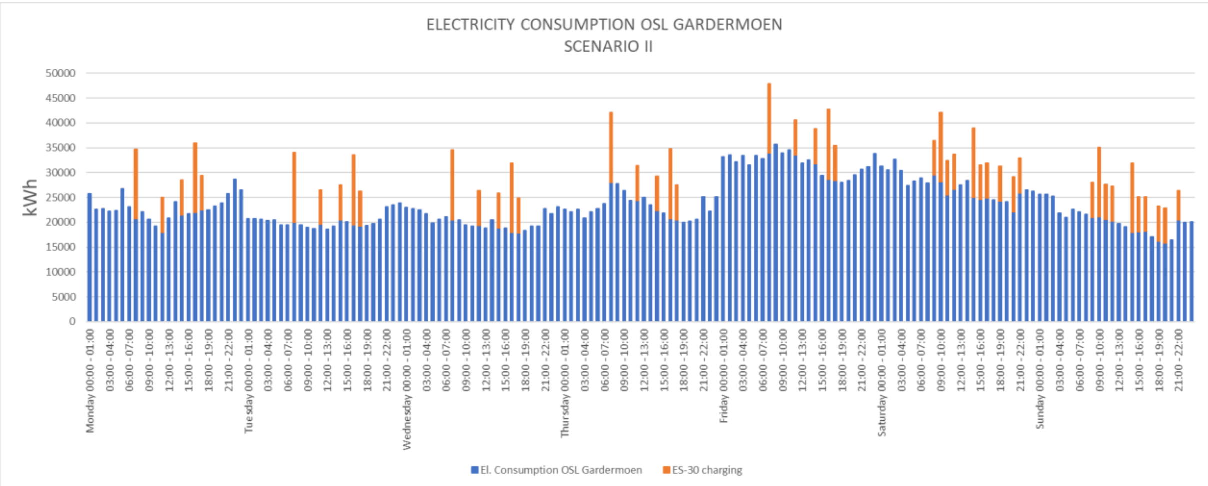

Figure 20:Charging patter ES-30, Monday - Sunday, Scenario II.

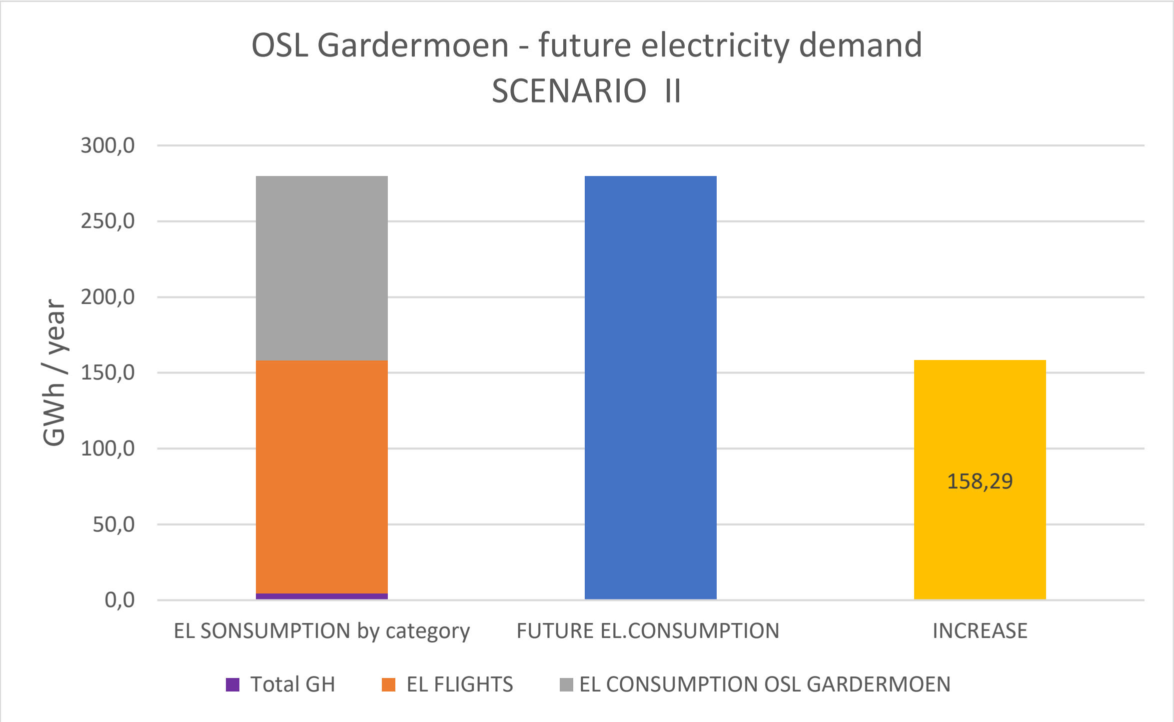

Figure 21: OSL Gardermoen - future electricity demand, Scenario II.

The peak-to-average ratio for electricity demand throughout the year shows the highest values in September (Table 13). As well as in Scenario I, the peak-to-average ratio has a direct impact on the power tariff since the price calculates based on the highest monthly power demand. The peaks throughout September can be moved to less demanding hours to reduce overall electricity costs.

On the contrary, the lowest value occurred in the month of December, where the total electricity consumption of OSL Gardermoen is impacted by low outside temperatures and high electricity consumption of district heating.

Table 13:Peak-to-average ratio of electricity consumption throughout the year 2022, Scenario II.

JANUARY			**JULY**		
Average demand	32827,69	kWh	Average demand	24196,90	kWh
Peak	73074,46	kWh	Peak	55149,60	kWh
Peak-to-average	2,23		Peak-to-average	2,28	
FEBRUARY			**AUGUST**		
Average demand	32895,74	kWh	Average demand	24612,90	kWh
Peak	72525,34	kWh	Peak	55721,95	kWh
Peak-to-average	2,20		Peak-to-average	2,26	
MARCH			**SEPTEMBER**		
Average demand	29245,81	kWh	Average demand	25040,27	kWh
Peak	65920,29	kWh	Peak	60140,24	kWh
Peak-to-average	2,25		Peak-to-average	2,40	
APRIL			**OCTOBER**		
Average demand	27810,36	kWh	Average demand	26868,46	kWh
Peak	63955,97	kWh	Peak	63576,55	kWh
Peak-to-average	2,30		Peak-to-average	2,37	
MAY			**NOVEMBER**		
Average demand	24855,48	kWh	Average demand	29531,15	kWh
Peak	58489,91	kWh	Peak	69651,32	kWh
Peak-to-average	2,35		Peak-to-average	2,36	
JUNE			**DECEMBER**		
Average demand	24535,08	kWh	Average demand	36711,15	kWh
Peak	55012,40	kWh	Peak	69853,55	kWh
Peak-to-average	2,24		Peak-to-average	1,90	

6.3 Scenario III

The result from Scenario III illustrates the outcome of charging the hydrogen aircraft for international flights from OSL Gardermoen. The yearly electricity demand in this scenario increases by 421,53 GWh (Table 13). When all three scenarios are combined, the annual electricity demand of OSL Gardermoen increases by 558,22 GWh/year, which represents increase of 459% compared to actual electricity consumption (Figure 22).

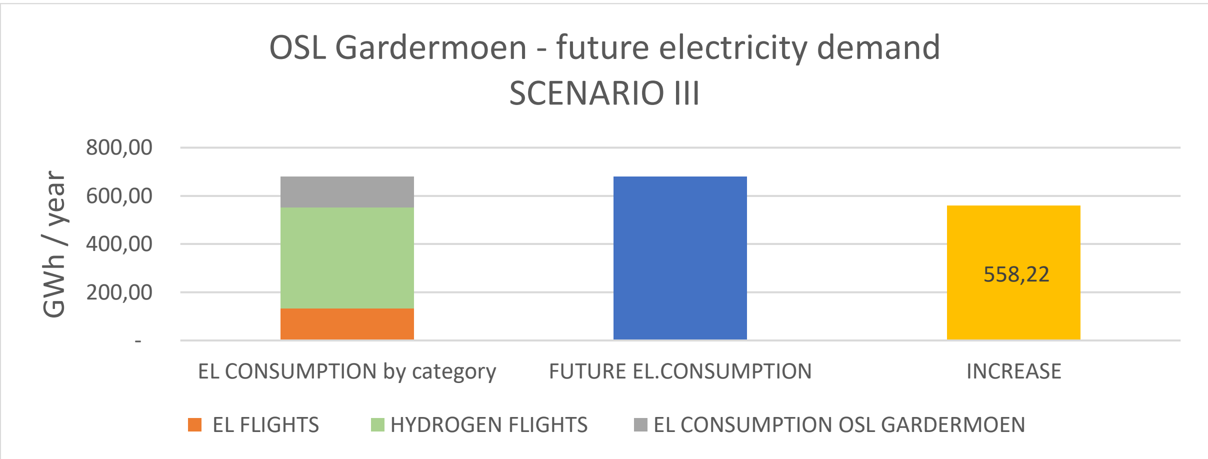

Figure 22:OSL Gardermoen - future electricity demand, Scenario II.

Table 14: Electricity consumption per day and per year for hydrogen flights, OSL Gardermoen.

TIME	El.Consumption/ flight		No of flights / hour	El. Consumption/ hour	
00:00 - 01:00	12,03	MWh	4	48,12	MWh
01:00 - 02:00	12,03	MWh	4	48,12	MWh
02:00 - 03:00	12,03	MWh	4	48,12	MWh
03:00 - 04:00	12,03	MWh	4	48,12	MWh
04:00 - 05:00	12,03	MWh	4	48,12	MWh
05:00 - 06:00	12,03	MWh	4	48,12	MWh
06:00 - 07:00	12,03	MWh	4	48,12	MWh
07:00 - 08:00	12,03	MWh	4	48,12	MWh
08:00 - 09:00	12,03	MWh	4	48,12	MWh
09:00 - 10:00	12,03	MWh	4	48,12	MWh
10:00 - 11:00	12,03	MWh	4	48,12	MWh
11:00 - 12:00	12,03	MWh	4	48,12	MWh
12:00 - 13:00	12,03	MWh	4	48,12	MWh
13:00 - 14:00	12,03	MWh	4	48,12	MWh
14:00 - 15:00	12,03	MWh	4	48,12	MWh
15:00 - 16:00	12,03	MWh	4	48,12	MWh
16:00 - 17:00	12,03	MWh	4	48,12	MWh
17:00 - 18:00	12,03	MWh	4	48,12	MWh
18:00 - 19:00	12,03	MWh	4	48,12	MWh
19:00 - 20:00	12,03	MWh	4	48,12	MWh
20:00 - 21:00	12,03	MWh	4	48,12	MWh
21:00 - 22:00	12,03	MWh	4	48,12	MWh
22:00 - 23:00	12,03	MWh	4	48,12	MWh
23:00 - 00:00	12,03	MWh	4	48,12	MWh
SUM DAY				1 154,88	MWh
SUM YEAR				421 531,20	MWh
SUM YEAR				421,53	GWh

7.0 Discussion

This chapter includes a discussion of all three scenarios and presents the advantages and disadvantages of each scenario.

The most discussed solution to emission reduction in the last years is electrification. Scenario I, with four electrified domestic flights, resulted in 112% increase in electricity demand. While the increase may seem substantial, the shift to electric domestic flights is not as drastic as one might anticipate. The highest peak-to-average ratio of 2.14 will impact the costs of electricity consumption. Therefore, this result opens discussion and research about possible solutions, such as V2G charging. Scenario I benefit from CO2 emission reduction due to the replacement of fossil jet fuel. Moreover, the electric propulsion contributes to a noise reduction during take-off. The disadvantage of this scenario is its focus solely on four most popular domestic flights, while OSL Gardermoen operates 26 domestic flights (Wikipedia, 2023b). The inclusion of all domestic flights will increase the demand for effective charging, prompting the new solutions such as overnight charging, when the electricity prices are lower, or portable external batteries that can be charged and used on-demand. These new solutions can lead to different results.

Scenario II, with single hybrid aircraft and four electrified domestic routes resulted in 130% increase in electricity demand. Similar to Scenario I, the peak-to-average ratio of 2,4 will impact the costs of electricity consumption. Scenario II also benefit from CO2 emission reduction due to the replacement of fossil jet fuel and noise reduction from electric propulsion during take-off. Another benefit of Scenario II is preparedness of OSL Gardermoen to adopt significant quantities of SAF. While still facing challenges in its production, SAF remains the most promising solution to emissions reduction.

Scenario III, with implementation of hydrogen aircrafts for long-haul flights resulted in 459% increase in electricity demand. The lack of sufficient technical information regarding hydrogen aircraft resulted in implementation of many assumptions that can lead to different outcome and are the disadvantage of this scenario.

7.1 Limitations, uncertainties, and possible impact of assumptions

This paragraph will discuss the limitations of this master`s thesis, as they provide a context for interpreting the findings and suggest directions for future research.

The primary limitation of this thesis lies in the insufficient advancement of zero-emission aircraft technology. Electric, hybrid and hydrogen-powered flights in the commercial sector remain theoretical and have not reached practical implementation levels yet. The planned operation of the electric aircraft is set for 2028, though numerous variables could alter this timeline.

The battery capacity assumed in Scenarios I and II might vary in the future due to the technical improvements. A larger or smaller capacity of the battery can shorten or extend the flight range, which has a direct impact on the possible final destinations. The time required for battery charging holds crucial role when modeling the charging schedule. To simplify the data work, battery of 1 MWh was assumed to charge at 1C rate. However, the charging rate may change due to the different future flight schedule. If all domestic flights in Norway were to be electrified, other airport infrastructure would certainly be needed for more efficient electric aircraft charging.

A possible impact to consider is the uncertainty around flying habits and air travel prognoses. The International Civil Aviation Organization predicts the continuous growth, yet the last years of Corona virus, war in Ukraine, Izrael; and the economic situation bring the uncertainties for the future flying habits.

8.0 Conclusions

From the analysis of three scenarios aimed at emission reduction in aviation, it's evident that electrification and SAF emerges as a significant solution. Scenario I and Scenario II both showcase the benefits of electric propulsion in reducing CO2 emissions and noise during take-off. However, they also highlight the considerable increase in electricity demand and the challenges associated with managing peak-to-average ratios, impacting the costs of electricity consumption.

On the other hand, Scenario III, revolving around hydrogen aircraft for long-haul flights, demonstrates a substantial increase in electricity demand. Yet, it also exposes the limitations and uncertainties stemming from insufficient technical information and numerous assumptions made in its implementation, underscoring the challenges of adopting emerging technologies.

In conclusion, while electrification shows promise in reducing emissions and noise pollution in aviation, the challenges of managing increased electricity demand, technological uncertainties, and the need for broader infrastructure improvements remain significant areas for further research and exploration in the pursuit for sustainable aviation solutions.

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Appendices

APENDIX A

Fossil Fuel Consumption – ground handling, 2022 (A. Rognan, personal communication, 1.12.2023).

FOSSIL FUEL CONSUMPTION			
Ground handling			
SGH	Diesel	451095	liter
SGH	Gasoline	59	liter
Menzies	Diesel	176991	liter
Menzies	Gasoline	5712	liter
Gate Gourment	Diesel	94325	liter
Gate Gourment	Gasoline	744	liter
Sodexo	Diesel	37144	liter
Sodexo	Gasoline	0	liter
TCR	Diesel	8339	liter
TCR	Gasoline	0	liter
SSP	Diesel	11567	liter
Norwegian Air Shuttle ASA	Diesel	14208	liter
Norwegian Air Shuttle ASA	Gasoline	11	liter
OSCC	Diesel	2268	liter
OSCC	Gasoline	0	liter
Sam Aero AS	Diesel	10773	liter
Sam Aero AS	Gasoline	11	liter
Scan GSE AS	Diesel	21306	liter
Scan GSE AS	Gasoline	11	liter
West Air Sweden AB	Diesel	767	liter
West Air Sweden AB	Gasoline	0	liter
Access Oslo	Diesel	475	liter
Access Oslo	Gasoline	0	liter
WGH	Diesel	44925	liter
WGH	Gasoline	149	liter
AFS Aviation Fuel Service	Diesel	41405	liter
AFS Aviation Fuel Service	Gasoline	1127	liter
Newrest Inflight Logistics Norway AS	Diesel	15379	liter
Newrest Inflight Logistics Norway AS	Gasoline	245	liter

Biodiesel consumption OSL Gardermoen, 2022 (A. Rognan, personal communication, 1.12.2023).

BIODIESEL CONSUMPTION			
Ground handling			
SGH	biodiesel, 2GPolar	0	liter
Menzies	biodiesel, 2GPolar	4167	liter
Gate Gourment	biodiesel, 2GPolar	265	liter
Sodexo	biodiesel, 2GPolar	107	liter
TCR	biodiesel, 2GPolar	60	liter
Norwegian Air Shuttle ASA	biodiesel, 2GPolar	3699	liter
Sam Aero AS	biodiesel, 2GPolar	17	liter
WGH	biodiesel, 2GPolar	124	liter
AFS Aviation Fuel Service	biodiesel, 2GPolar	1	liter
Newrest Inflight Logistics Norway AS	biodiesel, 2GPolar	78	liter

APENDIX B

- Flight Schedule OSL Gardermoen – Kristiansand (AVINOR, 2023).

WEEKDAY	
DEPARTURE	ARRIVAL
OSL Gardermoen	KRISTIANSAND
08:20	09:20
14:10	15:10
16:55	17:55
19:50	20:50
20:00	21:00

WEEKEND	
DEPARTURE	ARRIVAL
OSL Gardermoen	KRISTIANSAND
14:20	15:20
16:25	17:25
21:55	22:55
22:05	23:05

- Flight Schedule OSL Gardermoen – Bodø (AVINOR, 2023).

WEEKDAY	
DEPARTURE	ARRIVAL
OSL Gardermoen	BODØ
08:30	10:00
08:35	10:10
12:45	14:15
15:30	17:00
15:30	17:00
17:10	18:40
17:30	19:00
17:30	19:00

WEEKEND	
DEPARTURE	ARRIVAL
OSL Gardermoen	BODØ
09:15	10:45
10:30	12:00
10:40	12:10
11:00	12:30
12:40	14:10
15:00	16:30
15:00	16:30
15:30	17:00
17:30	19:00
19:00	20:30
21:00	22:30
22:10	23:40

- Flight Schedule OSL Gardermoen – Bergen (AVINOR, 2023).

WEEKDAY		WEEKEND	
DEPARTURE	**ARRIVAL**	**DEPARTURE**	**ARRIVAL**
OSL Gardermoen	BERGEN	OSL Gardermoen	BERGEN
07:00	07:55	10:40	11:35
08:00	08:55	12:20	13:15
08:00	08:55	13:20	14:!5
09:00	09:55	13:40	14:35
09:10	10:05	14:50	15:45
10:40	11:35	16:05	17:00
11:05	12:00	16:20	17:15
13:20	14:15	16:45	17:40
14:05	15:00	17:10	18:05
15:30	16:25	17:30	18:25
15:35	16:30	17:35	18:30
16:20	17:15	18:25	19:20
16:45	17:40	18:40	19:35
17:00	17:55	19:00	19:55
17:00	17:55	19:30	20.25
17:30	18:25	20:45	21:40
17:40	18:35	20:50	21:45
18:25	19:20	21:15	22:10
18:45	19:40	21:25	22:20
19:00	19:55	21:45	22:35
20:30	21:25	22:00	22:55

- Flight Schedule OSL Gardermoen – Stavanger (AVINOR, 2023).

WEEKDAY	
DEPARTURE	ARRIVAL
OSL Gardermoen	STAVANGER
07:00	07:55
07:00	08:55
08:00	08:55
08:05	09:00
08:55	09:50
09:05	10:00
11:05	12:00
12:00	12:55
15:00	15:55
15:15	16:10
16:15	17:10
16:15	17:10
17:05	18:00
17:15	18:10
18:10	19:05
20:30	21:25

WEEKEND	
DEPARTURE	ARRIVAL
OSL Gardermoen	STAVANGER
08:20	09:15
10:30	11:25
11:15	12:10
12:40	13:35
15:05	16:00
18:00	18:55
20:00	20:55

- Flight Schedule OSL Gardermoen - Trondheim

WEEKDAY	
DEPARTURE	ARRIVAL
OSL Gardermoen	TRONDHEIM
08:00	08:55
08:00	08:55
08:55	09:45
09:05	10:00
10:40	11:35
11:00	11:55
13:25	14:20
14:40	14:35
15:20	16:15
16:20	17:15
17:00	17:55
17:00	17:55
17:50	18:45
19:00	19:55
19:30	20:25
20:15	21:10
20:30	21:25
20:40	21:35

WEEKEND	
DEPARTURE	ARRIVAL
OSL Gardermoen	TRONDHEIM
10:35	11:25
10:40	11:35
13:25	14:20
14:00	14:55
14:30	15:25
14:40	15:35
15:20	16:15
15:30	16:25
16:20	17:15
17:00	17:55
17:20	17:15
17:50	18:45
18:30	19:25
19:00	19:55
19:15	20:10
20:00	20:55
20:10	21:05
20:15	21:10
20:40	21:35
21:50	22:45
22:00	22:55

APPENDIX C

Table 15: Average number of flights per day over a month (AVINOR, 2023).

Date	Number of flights
01.01.	112
02.01.	116
03.01.	110
04.01.	125
05.01.	119
06.01.	100
07.01.	138
08.01.	125
09.01.	86
10.01.	99
11.01.	115
12.01.	115
13.01.	85
14.01.	127
15.01.	108
16.01.	81
17.01.	89
18.01.	114
19.01.	113
20.01.	80
21.01.	113
22.01.	104
23.01.	85
24.01.	94
25.01.	120
26.01.	115
27.01.	85
28.01.	122
29.01.	107
30.01.	87
31.01.	96
AVERAGE	106

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