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Author: Ranjith Radhakrishnan	
Programme coordinator: Stine Thu Johannessen Supervisor(s): Harald.N.Røstvik	
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I would like to start my thesis with these words that had been my inspiration to choose a thesis related to renewable energy in the Airport.

"If we think terraforming of Mars into Earth is possible, then it is possible to terraform Earth into the Earth that can sustain living beings."

PREFACE

"Time flies, it's just like I have landed here in Norway, and already it had been two years of unforgettable memories that this land has given me, both academically and personally. This journey has been filled with lots of ups and downs. Finally, the day is here. I'm standing in front of the door for submitting my report, filled with so much excitement. I enjoyed working on "Energy at Airports." The delivery of the study feels fantabulous.

First of all, I am grateful to Harald N. Røstvik, my supervisor, without whom this research would not be complete. I feel that I am fortunate enough to work under him, who, for me, is the best in the business who had maneuvered me with a lot of ideas and concepts regarding planning not only in this thesis but also from the first day I met him without whom this report wouldn't be realistic.

I would like to thank Ingvald Erga, along with Jeanette Sandsmark, for allowing me to take this thesis with Avinor and for providing me with the data that is so essential for this report. The skype meetings and the time that you have allotted for this report is commendable.

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My sincere regards to my roommates, who were so supportive and were always with me during late nights to study and to keep me engaged. You have always stood my side helped me to face difficult times of corona. Thanks for that midnight study schedule. My sincere wishes to your thesis as well, brothers.

Finally, I would like to thank my parents, friends, and professors from the city and regional planning and for all their valuable time, lectures, information, and ideas that I have used in this report."

If anything can be done regarding transforming Energy in this world, it could be only with the help of Solar energy.

"Solar Energy is the only form of energy that has no negative Environmental side effects" (Nordic council Report 1986)

ABSTRACT

Airport's primary role is to provide passengers and freight connections to air travel. Over the past 20 years, the number of air operations has increased rapidly, leading to increased airport energy needs to meet this demand. Consequently, airports' energy procurement prices have risen. Around the same time, world energy demand has been increased because of the requirements of developing countries with the resulting impact on the climate. Airport authorities incur a tremendous amount of energy bills. This dynamic environmental and economic impact scenario has made airport authorities aware of the need to minimize energy usage and use it more effectively. But sadly, irrespective of the energy that they use or the amount of CO_2 that they emit, it is unaccountable.

Moreover, all airports, including Sola Airport, are dependent on the electricity generated from conventional energy sources such as coal, natural gas, hydropower, etc. Thus, right from the time of its construction, airports cause environmental pollution (Ko, Jang, & Kim, 2017). The PV installation may be an initiation of something that can inspire other institutions and government and non-government buildings to install PV panels and obtain clean energy from solar power. Besides, only the landscape on which the panels are used to harvest energy differs. Once the energy is harvested, the panels can be used elsewhere (Sreenath Sukumaran a, 2017).

This research paper analyses the energy distribution, consumption, and demand at Sola Airport. It discusses the various energy scenarios, along with different energy harvesting possibilities and techniques that could be well adapted at the airport. Energy mapping and management play a vital role in understanding energy usage and the conservation of energy by various means of regulations and practices. Energy scenarios and simulations were made in accordance to compare future energy needs following the functions of PED. The energy demand from both electricity and heating is considered when we evaluate a system to be a PED. But in this specific case, only the direct electricity demand is considered as the heating, and cooling needs are taken care of by wood and waste burning facility that is situated near the airport. Some claims have been found that there have been a savings of 2000 tons of CO_2 equivalent is being saved by this process. This report also discusses the same. Battery technology, electricity credits, and electrification of Airplanes were studied in the latter half of the report.

Relevance to Planning

Aviation Emissions

Airplanes generate greenhouse gases, predominantly carbon dioxide (CO2), from burning coal, which causes global warming in the atmosphere when released. As per a calculator from the International Civil Aviation Organization of the United Nations (ICAO), an economical return flight from London to New York generates approximately 0.67 tons of CO2 per traveler. That's around 11 percent of someone in the UK's total annual emissions, or around the same as those generated by somebody residing in Ghana for a year. According to the International Air Transport Association (IATA), aviation contributes about 2 % of global carbon emissions. It forecasts passenger numbers doubling to 8.2 billion in 2037. And like other economic sectors become eco - friendly, such as wind turbines, the percentage of total emissi ons from aviation is expected to increase (BBC News Report, 2019).

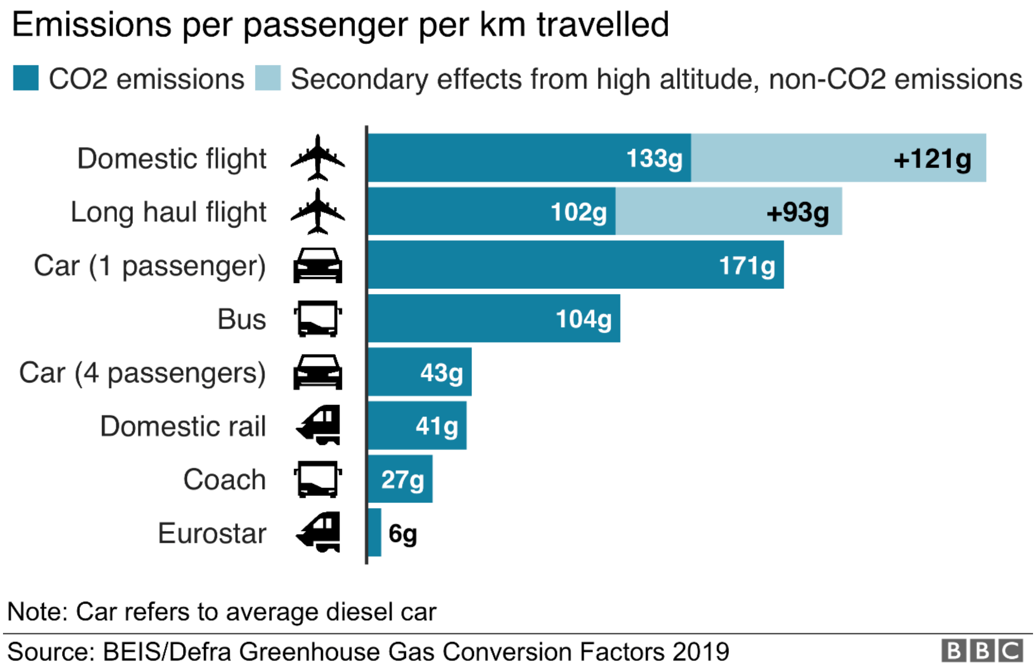

Figure 1 Emission from different modes of transport (BBC News Report, 2019)

Variations in Emissions

Variation in emissions depends on where passengers are seated and whether they take longer or shorter flights. According to the Department of Business, Energy, and Industrial Strategy (BEIS), CO2 emission per passenger per km travel was approximately the thrice for business class flights and four times higher for first-class flights. It is that there is more room per seat, so each individual contributes to a higher amount of aircraft pollution in the business class flights. Take off of aircraft consumes more fuel than gliding. It reflects a higher proportion of the journey for shorter flights. And that means lower direct flight emissions than multi-city journeys. Besides, newer aircraft will be more productive, and some airlines and routes can fill seats better than others. One analysis revealed a significant variance per traveler emission for different carriers (BBC

News Report, 2019). Due to an increased number of passengers, there will be a massive amount of energy demand and consumption in airports. Switching to renewable energy sources will be the key to make the airports' carbon neutral and energy independent.

Emissions also vary from airport to airport depending upon factors like the population of the city near which the airport is located, the number of travelers using the airport, energy policy of the airport, location of the airport, climatic zone of the airport location, construction quality and building planning of the airport, etc.

Thesis Relevance with Planning

Without even considering the pollution created by individual airplanes, aviation is one of the most polluting industries in the transportation sector. Transportation being a core theme in all Urban Planning, it is crucial to study the possibility of electrifying airports with renewable energy sources(here it is solar energy). This study focuses on the sustainability and self-sustenance of airports as a Positive energy district(PED), which is moreover a grid that has a lighting system, transportation, heating, and cooling needs. It is more comparable to any other structure that can be powered by solar energy. Small district electric planes, for instance, from Stavanger to Bergen, will play a significant part in strengthening the transport links from the city to Airport by a clean means, thereby building lots of roads. In the urban context, the relation between Air and road transportation will change completely. Here we are looking at a different type of transportation model, which is interlinked with city planning. This study also focuses on solar panels that will be installed on buildings and landscapes, which are transferrable to other components of the city structure.

Moreover, Airport itself is like a city, and it can help in understanding the city from an energy point of view. An airport is more or less like a small village or a part of a small city, as it has buildings, roads, offices, transportation systems, shops, restaurants, cars, vehicles, parking, parks, lighting systems, and planes around it. Energy use and its types are as crucial as the health issues of the people and travelers.

Figure 2 Airport city (Pinterest) with a renewable source, EV and EMS

Challenges

Despite various background documents that were given to us by the representative of Avinor, it was very crucial that much of the critical information, including daily consumption of energy at the airport, distribution of energy to various components at the airport, distribution of energy to various appliances, were not available. Those details were assumed and observed as a benchmark from other reports. Corona Pandemic has been quite a challenge because of which it was not possible to visit the site and to meet the airport authority to understand the project better. Most of the interviews and questionnaires that were planned before the research could not be completed. Even mail communications were limited as a total of 25 number of Airport authorities were mailed, requesting a meeting to guide about energy consumption and pattern at the Airport. But only three airport authorities replied in which one of them shared the data. All other web meetings that were scheduled also got canceled due to this pandemic.

Moreover, the University of Stavanger, along with other universities in Norway, was also closed most of the time during the thesis that restricted the usage of the university library and other facilities such as work areas and classrooms. It would have been more efficient to work from the university and the facilities than inside four walls of the home. This study is formulated based on different scenarios and is subjected to the assumed conditions. Extensive research is needed on energy consumption and distribution to analyze the proper BAU at Stavanger Airport. Based on future technology, the scenarios and the results obtained in this research is subjected to variations.

INTRODUCTION

Electricity has become one of the critical factors for the economic growth of communities, particularly in remote areas with disadvantaged access to modern power. One of the global community's fundamental problems is to reduce the gap in energy supplies amongst OECD and developing countries. Electricity provides the essential basis for economic, social, and human development, with significant effects on growth, healthcare, literacy, climate change, food and water conservation, and communication systems according to several various organizations such as the United Nations, the World Bank, and the International Energy Agency. Estimates by the International Energy Agency (IEA) suggest that by 2030 nearly 16% of the world's population will already lose access to electricity unless new measures are implemented to reduce energy poverty. A renewable energy roadmap needs to be built to increase the global electrification rate, starting with energy management planning. Sustainability refers "to responding to today's needs without compromising the ability of future generation to cope with their needs," according to the UN report "Our common future." In this respect, a sustainable energy plan entails energy production in present countries focused on increasing renewable generation and energy equality from other areas. While at the same time, moderating energy use and reducing CO2 emissions related to energy use (Elisa Peñalvo-López 1 ID, 2017).

As we all know, airports are large energy users, but this also implies that they have a massive energy-saving capacity. Airport operators have as their strategic goal the elimination by 50 percent of their 2005 rate of CO2 pollution before 2050. For this, the best possible approach must be applied. The use of resources in airports is split into two sections, power for electricity and power for heating. Let's focus specifically on their electricity use and power-performance optimization. Airports generate energy up to 180 M KWh a year, and terminals use nearly 60% of this. The other 40% of the charges are for airfield illumination, hangars, car parks. And other ancillary buildings associated with the Airport (Schluneger, 2015). The electricity produced by the device depends on the type of system, alignment, and useful solar resource (the sum of energy from the sun reaching the surface of the Earth, which differs according to a geographical area). Higher solar power means that more energy from the sun enters the body, which is suitable for PV system performance (Schluneger, 2015).

Background

The research was planned by Norconsult AS for Avinor AS / Stavanger Airport. The study's overall objective is to investigate whether Stavanger Airport can be self-supplied with renewable energy sources by 2025 with the installation of energy generation and storage systems. The initiative seeks to achieve the goal of Avinor, halving its own cumulative controllable greenhouse gas emissions by 2020 and helping to minimize greenhouse gas emissions from customer service and air traffic. Stavanger Airport has a broad, "pre-regulated" area available for building power generation facilities, primarily based on sun and wind. Enova supported the study of innovative energy and climate solutions in buildings, areas, and energy systems under the Conceptual Assessment Program. (Avinor AS, 2018)

Twenty solar panels were fitted loosely on flat roofs at the Sola airport. Both boards are wired to a 4.6-1 string inverter with Fronius primo. A separate power optimizer is mounted on each panel to ensure that each panel can optimize the available solar radiation. The optimizers are a sort of Tigo Maximizer TS4-RO MC4. Solar radiation on the device is measured by a Solar-Log Sensor panel, mounted directly south-facing from the roof surface at an angle of 15 degrees. Just as many mono-crystalline and polycrystalline modules have been installed, two panels of each shape are mounted in each direction/angle. The production of electricity from different equipment has been recorded. A total of 2127 KWh were derived from 10 mono-crystalline panels in the previous year. The ten polycrystalline panels born a total of 2042 KWh. Since the mono-crystalline panels used in the test unit have a higher power rating (285 Wp) than the polycrystalline panels (265 Wp), the specific advantages of the panels should be compared: the ten mono-crystalline panels had an extraordinary power of 746 KWh / KWp per year. The ten polycrystalline panels were projected to produce 771 KWh / KWp this year (Avinor AS, 2018).

Description

Stavanger Airport, Sola, has the intention to be fully self-sufficient by 2025. A project review will be carried out to identify creative energy and the environment approaches at Stavanger Airport to become self-sufficient with resources for building by 2025. ENOVA was submitted for concept evaluation. The project includes, but is not limited to:

- EMS system for energy management and energy equalization (optimal loading and renewable energy consumption)
- The solution to replace a diesel-powered emergency power unit with, for example, innovative battery solutions.
- Solution for energy storage.
- Rapid loading of bus and taxis.
- Renewable electricity production – e.g., solar panels, windmills, hydrogen, etc.
- Renewable heating solutions – e.g., ground heat, seawater heat, solar collectors, etc.

The conceptual evaluation will help Stavanger Airport look at the consumption of energy and search for the optimal solution for all energy users. This form of design evaluation would benefit other Avinor airports and have a significant transfer value for another 45 airports. The implementation of energy management and monitoring systems at Stavanger Airport is already underway. (Avinor AS, 2018).

RESEARCH QUESTION

To what extent can the Stavanger airport be transformed into a Positive Energy District with Solar Power, and including the possibility of fueling Electric Aviation?

METHODOLOGY

The analysis of the related literature reveals several energy-saving tools. The applicability and advantages of technological tools in energy forecasting are widely illustrated, enabling estimates and processing time reduction. In 2010, Connolly et al. focused on 37 programming methods to evaluate renewable energy incorporation into diverse energy technologies. All such tools, like Energy Plan or LEAP (Long-range Energy Alternatives Planning System), allow multiple alternative solutions to be compared to assess the pros and cons of various energy solutions. It helps to evaluate different energy roadmaps within a viable period. These tools have not been designed explicitly for verifying renewable hybrid decentralized systems that are aimed at sustainable energy demand in a specific area. I have also used a technique called SIMESEN ("Simulación de Escenarios Energéticos"—Simulation of Energy Scenarios) that is established at the Institute for Engineering Energy at the Universitat Politécnica de València. It employs a centralized approach to analyze different energy alternatives to transform a region, region, or country sustainable energy. It discusses the effect on the organization's electricity road map of innovative solutions. A comparison of two macro-level energy scenarios is given by the methods used. Business As Usual (BAU) and a green energy development scenario are identified. It contrasts the transformation of climate history with the organization's actual energy mix, focused on distributed renewable electricity production, with the HRES (Hybrid Renewable Systems). The HRES scenario investigates the impact of enhanced access by dispersed renewable hybrid systems to renewable energy in the organization. To define crucial factors and to measure renewable resources' commitment to a realistic goal, SIMESEN provides the ability to examine two possible routes (Elisa Peñalvo-López 1 ID, 2017). Finally, the results were compared to the functions of PED.

Making Stavanger airport, a zero-emission one with the use of only solar panel is a big deal. It requires a lot of analysis of reports, data from different sources on energy and efficiency of panels, orientation, and the total energy requirement of the particular Airport. There lie many other challenges in designing the energy storage possibility and system to be chosen. A Direct site analysis was made to inspect the options of installing the solar panels. Also, consider other considerations such as Glare from solar panels, electric aviation, etc.. Several literature studies have been analyzed along with a case study of different airports. A mixture of both qualitative and Quantitative analysis was done with the help of several background literature provided by Avinor AS and Norconsult AS. Few discussion sessions were very helpful in understanding the concept better. Some interviews have been obtained from several officials and professors to get some insights on Solar PV in Airport. Data for solar panel analysis and orientation is obtained from TIGO, which is again provided by Norconsult. Some of the software was also used to make this report and energy calculations. Software such as Sketch-Up, Adobe Photoshop was used for graphical and pictorial representations. Otovo, PV GIS, and PV Syst were very helpful in making simulations.

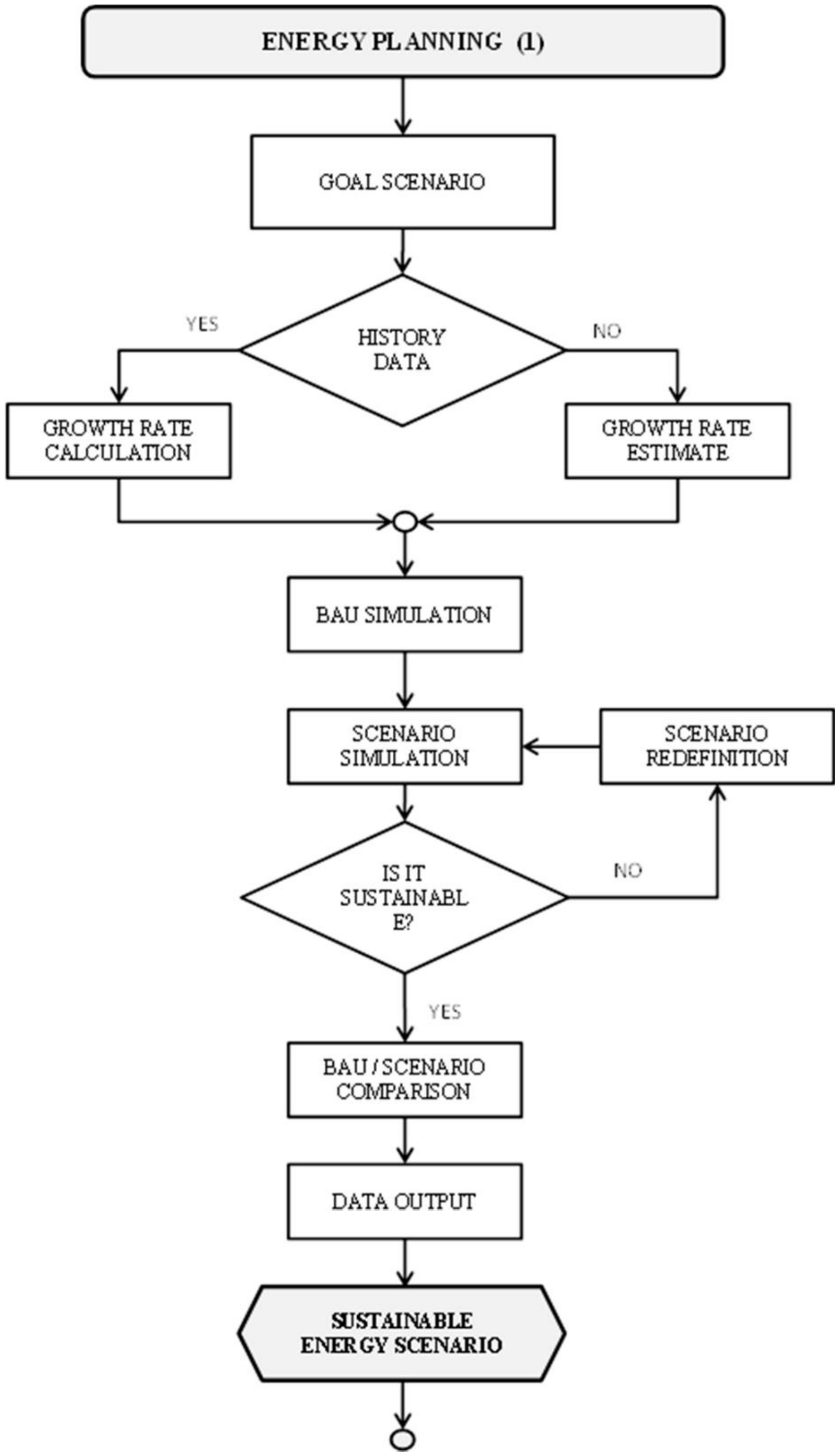

Figure 3. Methodology SIMESEN ("Simulación de Escenarios Energéticos"—Simulation of Energy Scenarios) for Energy Planning. (Elisa Peñalvo-López 1 ID, 2017)

This methodology is based on a linear model that connects demand to possible contributions from each primary source of energy and electricity. In energy modeling, the use of linear models to solve complex problems is customary. It describes the evolution of each and its related CO2 equivalent inputs. emissions to examine a variety of energy variables

Using document analysis, empirical data obtained for case studies were analyzed. Data analysis is also used in the case of studies, drawing on information and data from structured documents and business records. The papers collected for the thesis were analyzed on four criteria: validity, reliability, reproducibility, and meaning[. Before the systematic review of the documents collected in the report, the nature in which the reports were produced and the validity of the papers was assessed. Authenticity includes testing gathered records for their solidity and realism. Scott and Marshall (p. 188) note that "soundness" applies to whether the text is complete and whether it is an original and a sound copy. Authenticity involves things like collective or hierarchical attribution. The source of case study papers in this research was Cochin International Airport and Groningen Airport. Public domain records were open. The integrity criteria include record quality and sincerity. In the present study, proof for case analysis was corroborated using specific types of documents. To mitigate perceived bias, papers from different sources were analyzed. The predictive validity test included determining the quality and survival of the collected forms. In the current research, there were significant challenges in acquiring information as all relevant records were not available in the public domain. A considerable number of efforts and many emails have been sent to the airport authorities to get these documents.

In some cases, approval from higher officials was also required. Time is a significant concern. Many of the documents are still to be accessed. The fourth criterion, meaning, is a big concern, occurring at two stages. The first is a document's necessary interpretation, meaning its physical readability, the vocabulary used, and how it can be read and documented. When performing document analysis in a report, assessing the understanding and context through which the form was created is essential. It helps the researcher to view the document context. Proof contained in the study documents was consistent and comprehensible (Baxter, Srisaeng, & Wild , 2018).

The document analysis process of the study was carried out in six separate phases as follows:

- Phase 1: this step involved planning the types and documentation needed and their availability;
- Step 2: gathering the documents and designing and implementing a record management scheme;
- Phase 3: evaluating the documents to determine their authenticity;
- Phase 4: the contents of the reports gathered have been investigated and main topics, details, and problems identified;
- Phase 5: improving and extracting the definition and challenges associated with the reports, checking the sources as well as examining the contents of the documents; and
- Phase 6: an examination of the documentation was done in this final step of the study (Baxter, Srisaeng, & Wild , 2018).

SITE ANALYSIS

Stavanger Airport, which is situated at Sola (SVG) is an international airport located in Rogaland, Norway, serving Stavanger City and Municipality. This Airport sits 11 kilometers southwest of Stavanger that is around 4.95 square kilometers in area. It is the third busiest airport in Norway, providing both fixed and offshore oil platforms traffic helicopters. Moreover, Westland Sea King runs search and rescue helicopters in the Royal Norwegian Air Force at Sola Air Station. In 2015, Sola served approximately five million travelers. As early as 2008, Sola was one of the first airports in Norway to use self-service bag-drop-units. Sola now has twenty state-of-the-art bag-drop locations to sell passengers with its latest addition. Sola's approach for self-service bag drop is exceptional because it features an optimized empty tote system. Passengers traveling with rucksacks and similar can automatically get an empty tote for their baggage (BB Computerteknikk AS, 2019).

Figure 4 Sola Airport

The total allocated area for the construction of solar panels is about 22 hectares, and for now, an advisor is planning to start with two hectares initially as a trial project. The energy that is obtained will be used for running of airport terminal buildings as well as charging the electric busses. On account of solar sunshine and surplus of energy that may be obtained on a sunny day in Stavanger, it shall be sold to the Harbor in Stavanger rather than selling it to the grid that they think as unprofitable. Selling to a neighbor is also an option, but it is not allowed as of today's situation. Buildings are not the obvious choice for mounting solar panels due to maintenance that will be happening two years once on the terrace (mounting and unmounting of the panels costs more and is a burden). The only building that would likely have a solar panel is the new parking building that is being built in the Airport.

Siting Considerations for Airports

Other considerations must be addressed when building solar systems in or around the airports in addition to the above specifications. Systems must be located within a suitable distance from the path and comply with appropriate safety and fire measures. There is no specific distance as of standoff distance, but all scenarios must be considered before laying the panels on the Airport Fields irrespective of the distance from the runway. (Romero, 2014).

In this specific case of Sola Airport, there is no plan to install any solar panel near to the runway or on the terminal buildings. The solar power plant will be situated as far as 50 meters from the runway, which is the more appropriate distance to have any type of installation. Therefore, the safety measures from aircraft will be well accounted for with such placement of solar panels.

Figure 5 First Phase of Solar Farm marked in Red (COWI AS , Avinor AS, 2020)

Wind and Temperature Data

Solar modules are manufactured at Standard Test Conditions (STC). Still, in a specific area, environmental factors such as ambient temperature and wind speed may impact the module 's output for that particular region. The efficiency of the solar module varies depending on the specific location and prevailing environmental conditions. The efficiency of photovoltaic panels' energy output varies with climatic factors. Because at any moment, the strength of radiation increases, the generation of energy by the solar cells must also change. It was observed that the power generated by the PV systems is still highly dependent on weather factors at a particular instant.

Module efficiency depends on environmental factors. Data such as solar radiation, atmospheric temperature, relative humidity, and wind speed are recognized and sound renewable energy sources. Researchers have considered various types of modules and arrays tested in various environments in different regions. The manufacturer's specification does not necessarily provide the same results when evaluating the efficiency of the PV system; hence local environmental parameters should be considered (Bhattacharya, Chakraborty, & Pal, 2014) The below image shows the average wind speed, wind direction, wind strength distribution and temperature of Sola Airport.

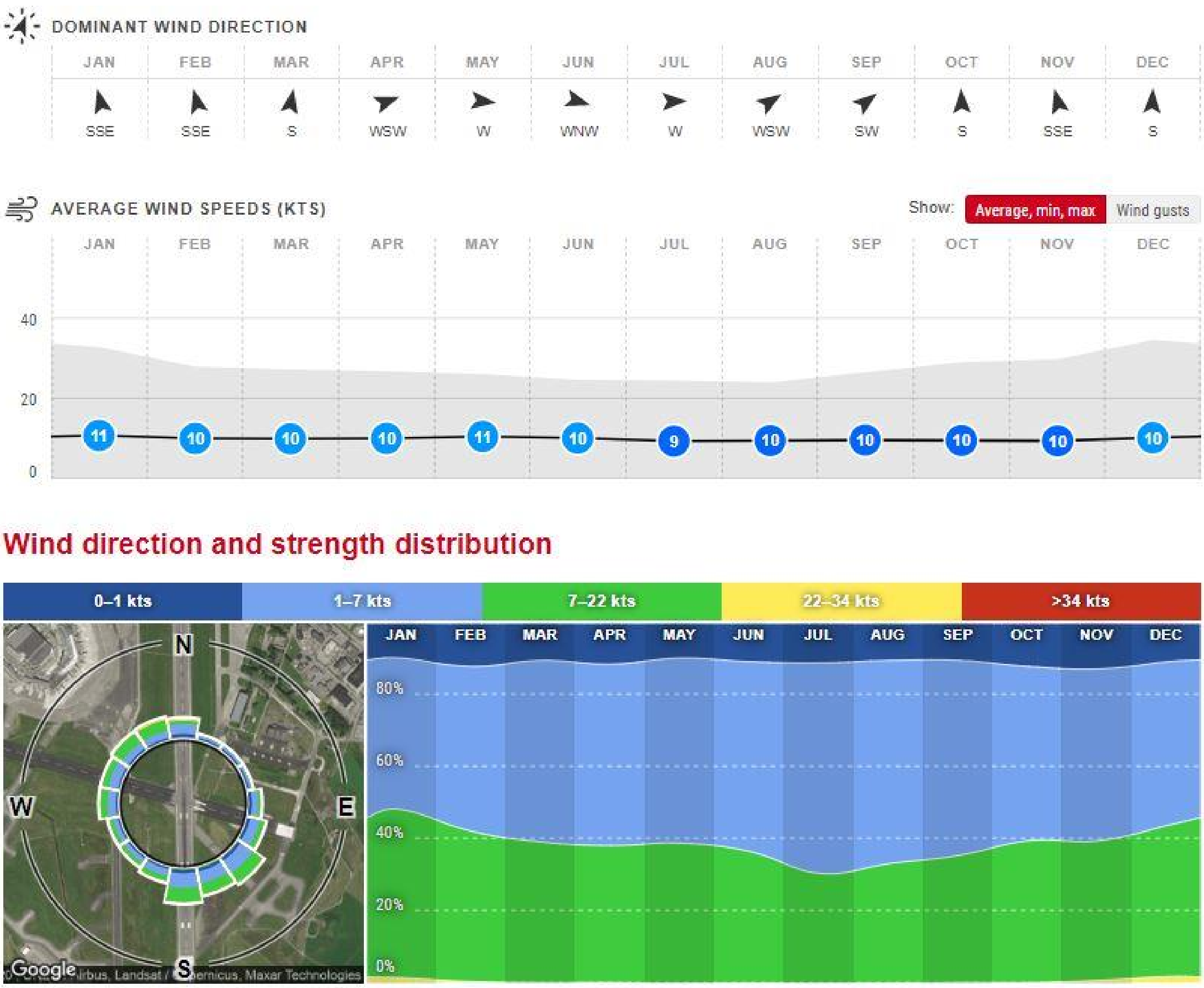

Figure 6Monthly Wind Direction and Wind Speeds at Sola Airport (WindFinder, 2020)

Temperature averages for Stavanger lufthavn/Sola

AVERAGE DAYTIME TEMPERATURES (°C)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MAX	11	43	24	28	29	28	32	29	26	22	16	12
AVG	3	3	5	8	12	14	17	17	14	10	6	4
MIN	-15	-32	-13	-5	1	1	9	6	2	-4	-11	-14

AVERAGE NIGHTTIME TEMPERATURES (°C)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MAX	10	9	13	18	28	26	29	28	22	19	22	12
AVG	2	2	3	6	9	12	15	15	12	9	5	4
MIN	-17	-13	-13	-5	-1	4	7	6	2	-4	-12	-15

Figure 7 Monthly Temperature Data at Sola Airport (WindFinder, 2020)

LITERATURE REVIEW

Many kinds of literature have been used to study the current situation of the energy demands and energy-efficient measures adopted by Stavanger airport to minimize its usage of energy and switch to clean energy. Some of the insights of the reports are as follows.

Positive Energy District

Positive Energy District (PED) is referred to as "Positive Energy Districts are energy-efficient and energy-flexible urban areas or groups of connected buildings which produce net-zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy. They require integration of different systems and infrastructures and interaction between buildings, the users and the regional energy, mobility, and ICT systems while securing the energy supply and a good life for all in line with social, economic, and environmental sustainability." (Hinterberger, Gollner, Noll, Meyer, & Schwarz, 2020, s. p7).

Functions of a Positive Energy District (PED)

The interpretation of the PED should not just only be an application for the measurement of energy input and output but more of a structure that describes the three most significant functions of city environments within their urban and regional energy system. The apparent primary requirement, which is one of the key contributors to climate neutrality, is that PED's ultimately rely only on renewable energy, explains the energy production function. Secondly, energy conservation should be deemed a priority to allow the maximum use of available renewable energy that explains the energy efficiency function. Thirdly, since urban areas are expected to be among the primary energy consumers, PED has to ensure that it functions in an ideal way that accounts for energy flexibility function in the energy system. (Hinterberger, Gollner, Noll, Meyer, & Schwarz, 2020).

All these three functions are interlinked to each other and contribute to one another to achieve a balance that best represents the available renewables in their respective climatic areas. Cities should be able to optimize the different functions and guiding principles to each other, along with their specific ambitions and needs. When designing PEDs, consideration must be taken of the particular urban environment (e.g., density, a form of buildings, local renewable energy resources available) (Hinterberger, Gollner, Noll, Meyer, & Schwarz, 2020).

Energy Flexibility function

PEDs' core objectives and activities in terms of energy versatility are

- to contribute effectively to the stability and sustainability of the regional energy system to maximize the advantages of the national energy system. For urban districts/neighborhoods, as the critical energy users in the energy sector, demand-side control, linking, and storage are the primary resources for this purpose.

- To handle all communication between municipal and national energy structures such as carbon neutrality and 100 % renewable energy for local consumption and a potential over-year surplus of renewable energy.

Energy Efficiency Function

The goal of the PED system is to maximize energy use, meet the demands of the various sectors, to build infrastructure, energy use, a conceptual model of settlements and transportation and accessibility. Due to its significance, it is not only better to improve new urban developments but also the current housing stock. Mixed-use communities, for example, may act as an efficient method to reduce transport needs.

Energy Flexibility Function

Planning of roads, infrastructures, and improved and efficient way of transport to the airport such as electric busses, buses that run with solar production of its own(solar mounted buses) and various other modes of transportation shall also play a considerable role in transforming the airport into a Positive Energy District.

Energy Production Function

The renewable energy generated locally and regionally would dramatically reduce greenhouse gas emissions and provide commercial feasibility. However, the local renewable energy production depends heavily on local and national factors and the preferred directions for the transformation of the European and global energy grid. The use of waste heat is promoted in particular (Hinterberger, Gollner, Noll, Meyer, & Schwarz, 2020)

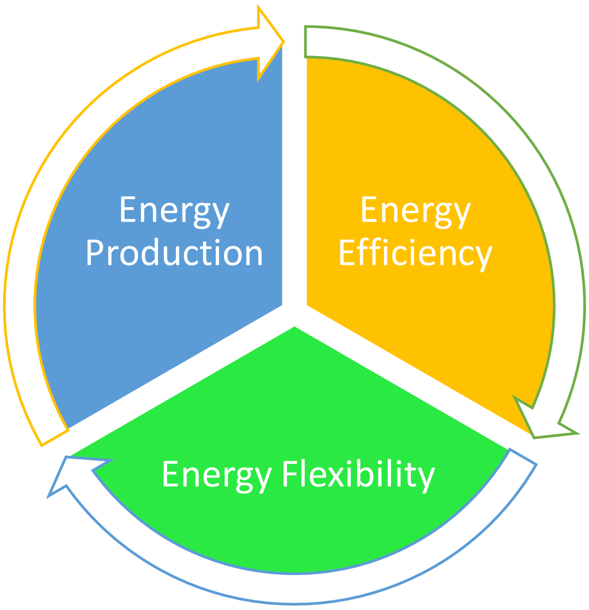

Figure 8 Functions of PED

Each PED, on the way through climate neutrality and energy surplus, must strike its optimum balance between energy conservation, energy sustainability, and local-regional energy output, and do so considering the critical guiding principles (Hinterberger, Gollner, Noll, Meyer, & Schwarz, 2020).

Fundamental Guiding Principles of PED

To make it desirable for cities and people, the implementation of PED should follow four core principles:

- Life quality
- Inclusion (with particular emphasis on affordability and energy poverty prevention)
- Sustainable development
- Resilient and secured energy supply (Hinterberger, Gollner, Noll, Meyer, & Schwarz, 2020).

Criteria for Sustainable Airports

The research involves the installation of Avinor on the Stavanger Airport barrier. The main meter 72707, is described as the source of these conceptual frameworks' electrical energy requirements. The critical measurement is located at St.3 intake (central Lyse information). Annual energy and power needs are calculated based on measured energy data and future need assessments. It is a target that through steps in the plant and implementation of a new management system and units for renewable energy production and Planning, renewable energy can generate the amount of power within a year. This principle allows the purchasing of electricity from the external supplier and the production and export of electricity at certain times. The concept should always be able to meet the given requirement for performance. Energy solutions for demand and production should be scaled up and can be progressively developed in line with future needs. Self-produced electricity is considered efficient energy for charging means of transport. However, energy needs for cars and aircraft are not considered independent as part of the energy demand. The system has to be tampered with to meet the increase in electricity needs. The heat generated from tile systems is known as autonomous, renewable energy (Avinor AS, 2018).

Power market and Capacity of Grid in Norway

Statnett expects development in Europe towards less thermal power generation and more renewable non-adjustable energy supplies. It provides a near balance and lack of available goods in some cases, but also excess times where un adjustable production covers consumption alone. It increases price disparities, but also incentives to improve grid flexibility. Grid companies plan NOK 140 billion in grid investments over the period 2016-2025. The analysis shows that the current grid power was, most of the time, improperly used. The socio-economic lychee is an expensive expenditure in resources used only for a while. A simpler and more efficient solution might be to cut spending stops and postpone or reduce investment in new networks. It is how the tariff increase can be reduced. These problems provide the background to the goal of the study to always have a specific installed impact. Stavanger Airport needs both power costs to control and versatility and protection for local ISPs and contributes to a proper network element in the region. (Avinor AS, 2018).

Energy Use Strategy

Fossil fuel-generated heat and electricity is typically the primary source of carbon emissions from an airport operator, so reducing reliance on this form of energy and increasing energy efficiency has been standard industry priorities for decades.

With current and projected growth, airport capacity and environmental impacts must be both increased and reduced – particularly by growing energy efficiency. To date, airports have a different manner of managing their energy efficiency levels. Airports that install solar panels invest in energy-saving green building designs, and use more efficient lighting and air conditioning systems, for example. The first step in tackling the energy efficiency levels of airports is to evaluate how much they use their resources. In collaboration with Transport Canada, the 2009 Carbon Emitting Monitoring Tool (ART) Airport is a free resource that allows airports to monitor their energy usage and related carbon emissions. When an emissions study is drawn up, airports are better prepared to prepare and use alternative energy sources and register their improvement of energy efficiency. Both experts and non-experts can use ACERT (Airport Council International, 2017).

The management of airport facilities ensures that a wide variety of energy and environmental issues are addressed. Administrators should reduce power usage and reduce airport carbon footprint, thus rising airport efficiency. Huge volumes are found in commercial airports. Fuel is also the second-largest airport operating expense, as airport staff has increased to a higher level of power usage due to fuel costs, combined diesel generators, and the legalization of fuels. To develop and make the investment strategies a priority we should improve

- Heating, ventilation, and air conditioning systems (HVAC) are typical cost-efficient upgrades.
- Controls of the building
- Adequate measurement and verification (M&V) and appropriate commissioning facilities will make sure that the equipment and systems conform to the expected requirements and achieve anticipated savings.
- Airport facilities can significantly reduce energy consumption by:
- Improved manufacturing and maintenance processes of utilities
- commissioning / optimizing new technologies for the use of electricity.
- Promoting effective management of the environment by reducing the use of natural resources.
- Developing solutions to energy saving.
- Identifying opportunities for clean, renewable energy. (Optimizing Energy Savings - Airport, 2012).
- Micro-measures – With growing airport travel and energy use, it is essential to introduce a versatile framework with the ability to support micro-measures. There is excellent scope for branch level control at airports (Schluneger, 2015).
-

Existing energy-saving measures under Practice

An airport requires a great deal of energy, but we are more focused on energy-efficient, heat-reduction, and further reusability. In 2014, authorities took some steps at airporter Sola, which is projected to save 3,000,000 KWh per year. It is equal to the average intake of 148 households.

Reuse of heat

In 2015, the buildings were used more. During transfers from a rebound to rotating ventilation, the hot air can be used even more frequently. The rotating recovery system absorbs heat by applying small laths to the rotor. The heat is discharged into the air again after a half-time period. The new airflow is intended to increase the use of hot air by 20%, thereby saving energy.

New pumps for the radiators

Airport heating and cooling systems were replaced with pumps that provide better-regulated energy efficiency. Where some of the old pumps have been running with constant water movement, the new frequency pumps are controlled by water requirements and ensure minimal energy consumption.

Heat pumps in the halls

As heat pumps were introduced to the worksite, the previously high-value energies used in electro boilers and electric radiator systems were replaced by a lower value because of more environmentally sound technology. Four heat pumps are now installed in two large halls of our house, extracting energy from the air and generating residual heat. It could save about 100,000 KWh per year.

Led lights

At the Airport as a whole, Led's has a significant replacement. Led lights require far less daily energy. Light sources have a very long life span and therefore contribute to less production and waste replacement (Avinor AS, 2020). The below table shows the energy-saving measures that are undertaken in sola airport and its equivalent savings.

Table 1 Saving Measures undertaken and actual savings in energy management (Avinor AS, 2018)

Measures	Saving [KWh/year]
1. Introduction energy management	**194 889**
2. Establishment EOS	**682 111**
3. Establishment operating instructions	**292 333**
4. Active energy ups	**Hanging with the remaining Measures**
5. Establishment attitude campaign tenants	**421 000**
6. Optimization of snow smelters	**69 888**
7. Seasonal focus	**9061**
8. Attitude campaign gates/doors	**10 280**
9. Rectifying meter structure – (winter 2018)	**194 899**
10. Operating optimization 2018	**590 999**
11. Remediation lighting and steering (spring 2019)	**646 280**
12. Upgrading automatics	**100 320**
Sum	**3 212 060**

Energy Management and Energy Saving

Saving energy for the airport can vary between 7,27% and 96,8%, depending on exterior temperatures. In lighting, the total savings for zero constructions was 14 percent and daylight 63 percent when considering other EM-factors, such as emissions-free, reduced energy, and passive building codes. Therefore, the possible savings for the daytime and duration are nearly 250,000 USD per year and 121,397 USD per year. Energy Analysis (EA) based estimates indicate that the energy-saving in terminal buildings is indeed a significant consideration of around Seventy percent of overall energy usage at the Airport. Ultimately, there is a possible saving half of the energy in thermal Planning and operations for the airport's terminal buildings (Uysal & Sogut, 2017).

Airport Carbon Accreditation

Airport Carbon Accreditation is the sole carbon assessment system for airports that are systemically approved. Carbon Airport Accreditation acknowledges and authorizes airports ' efforts to manage and reduce their co2 emission. Four levels of certification are: "Mapping," "Reduction," "Optimization," and "Neutrality." The Airport Carbon Accreditation ' reduction' process needs carbon management and development towards a low carbon emission (ACI EUROPE, 2009).

To reach this accreditation standard, an airport needs to meet all 'Mapping' criteria. And prove successful carbon control procedures like targeting. It will also demonstrate that the carbon footprint has been reduced when the carbon emissions estimates for consecutive years are evaluated. When an airport has measured its carbon footprint, its carbon emissions can be decreased. This method is called carbon management and includes several actions that an airport can take:

- Display low carbon / low-energy strategy
- Display a senior committee or body responsible for climate change/carbon/energy issues
- Demonstrate how it communicates pollution efficiency to stakeholders
- Display procedures for Planning and testing carbon footprints
- Monitor fuel / energy consumption
- Carbon / energy emission goals
- Have systems or monitoring mechanisms to reduce emissions
- Shows the carbon effect of investments
- Showing workers sensitivity training on pollution
- Display a self-assessment and audit process to track progress in improving execution (ACI EUROPE, 2009).

Specific examples of measures for carbon management have included:

- ***Reduction in energy requirements*** – well defined and efficient control through analysis, calculation, management, automatic meter readings (AMR), automatic monitoring, and targeting (AM&T).

- ***Clean energy supply*** – heat & electricity mixture, renewable energy sources (on-site or off-site).
- ***Low energy architecture*** – requirements for renovation and new building, mandatory incorporation of carbon reduction studies in all new projects.
- ***Alternative fuel vehicle options*** (electric, hybrid, hydrogen, LPG, etc.).
- ***Staff interactions and preparations for involvement.***
- Similar or preferential determination of ***carbon-reducing investment programs.***
- ***Technology*** to analyze and reduce supply-chain emissions (ACI EUROPE, 2009).
-

Best Practice Initiative

The below table is the snapshot of the Best practice initiatives that shows emission impact on BAU along with the payback term in years for the system. It also shows the scope of emissions for different components of an airport.

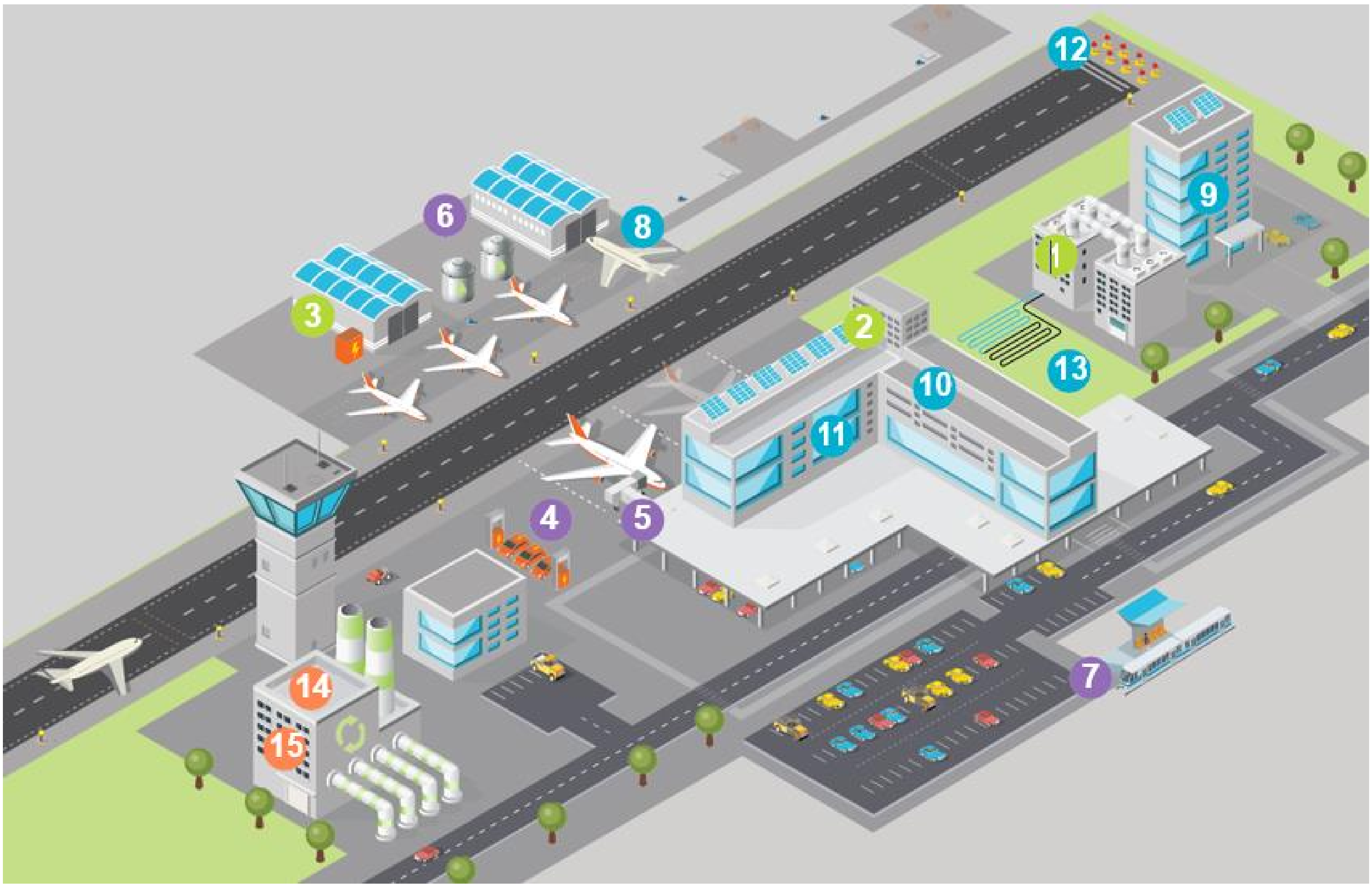

Figure 9 Best Practice initiatives (AECOM Australia, 2020)

Table 2 Best Practice Initiative (AECOM Australia, 2020)

Best practice initiative	Emissions impact as % on BAU	Capex as % asset value	Payback in years	Emissions scope	Location	Airport applicability
1. Central utility plant	Up to 25%	>0.5%	<20	1, 2	Landside Terminal Airside	Major airports
2. Onsite solar PV and battery energy storage	Up to 100%	<0.3%	<5	1, 2	Landside Terminal Airside	Major airports Regional airports
3. Purchasing renewable energy	Up to 100%	N/A	Variable	2	Landside Terminal Airside	Major airports Regional airports
4.Electrification of ground support equipment	Up to 100%	<0.5%	>10	1, 2	Airside Landside	Major airports
5. Fixed ground power and pre-conditioned air	Up to 40%	<0.5%	>20	2, 3	Airside	Major airports
6. Sustainable aviation fuel	Variable	<0.5%	Variable	3	Airside	Major airports Regional airports
7. Surface access improvements	Variable	>0.5%	>20	3	Landside	Major airports
8. Aircraft and airside upgrades	Variable	>0.5%	Variable	3	Airside	Major airports Regional airports
9. Building analytics technologies	Variable	<0.3%	<5	1, 2	Terminal	Major airports Regional airports
10. Low energy baggage handling systems	40-75%	<0.5%	>20	2	Terminal	Major airports Regional airports
11. Terminal initiatives	Variable	Variable	Variable	1, 2	Landside Terminal	Major airports Regional airports
12. Airfield lighting upgrades	Up to 50%	<0.3%	>5	2	Airside	Major airports Regional airports
13. Ground source heat pumps	20-50%	<0.3%	>5	1, 2	Landside Terminal Airside	Major airports Regional airports
14. Energy-from-waste	Variable	<0.5%	Variable	1, 3	Terminal Airside Landside	Major airports Regional airports
15. Waste minimization	Variable	<0.3%	>5	1, 3	Landside Terminal Airside	Major airports Regional airports

Carbon Footprint

A "carbon footprint" is the cumulative amount of carbon dioxide and other greenhouse gases produced during a process or product life cycle. It is demonstrated as grams of carbon dioxide equivalent per kilowatt-hour (gCO2eq / KWh) that reflects different global warming effects of other greenhouse gases. This section mainly deals with CO2eq pollution from the power supply in the life cycle. All other emissions are not covered by this study. The intensity of CO2 emissions (kg CO2 / KWh) is obtained both from the operational emissions from the generation source and the emissions produced during the construction of the sources. The Life Cycle Analysis (LCA) of the sources of energy determines the CO2 equivalent per KWh (Post Note, 2006) Coal has the highest consumption of 0.9 kg per KWh of electricity generation. The below table shows the source of CO2 and its equivalent per KWh.

Table 3 Co2 Equivalent Per KWh

Generation Source	kg CO2 per KWh
Open Cycle Gas Turbine	**0.5**
Closed Cycle Gas Turbine	**0.5**
Oil	**0.65**
Coal	**0.9**
Wood	**0.38**
Nuclear	**0.005**
Pumped Storage	**0.02**
Non-Pumped Storage Hydro	**0.005**
Wind Onshore	**0.00464**
Wind Offshore	**0.00525**
Solar	**0.058**

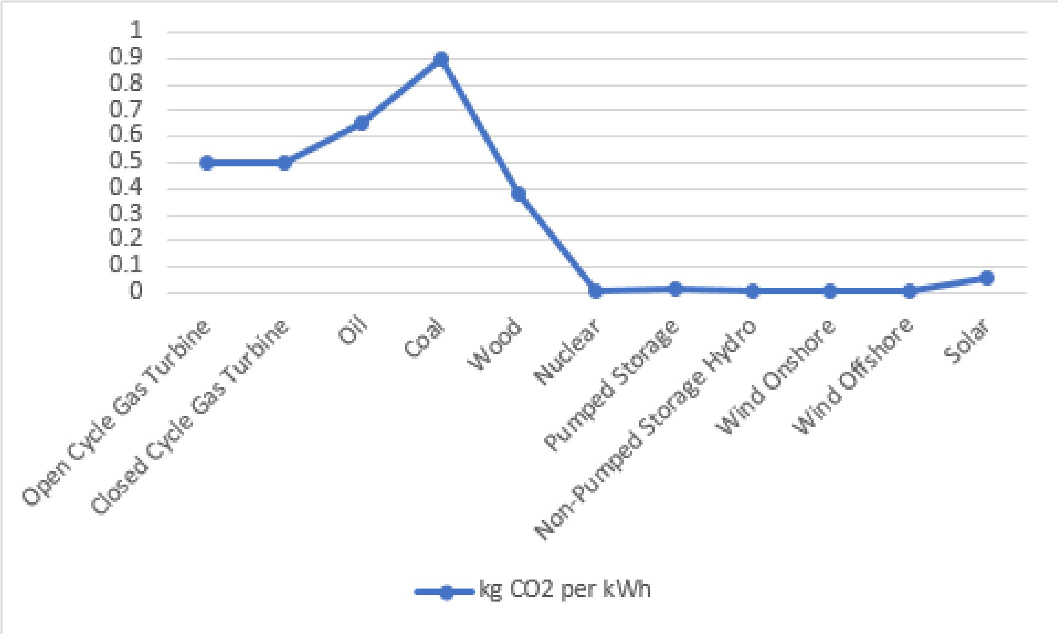

Figure 10 CO2 Equivalent per KWh

ANALYSIS

An airport is one or more aircraft runways along with associated buildings or terminals where commuters or airplane cargo is processed. Airports are a vital component of the world air transport network where airlines and commuters come together. The specific operations at an airport for which the airport management or owner is accountable vary significantly between countries and also between airports located in the same region for geographical, legal, and commercial reasons. In some instances, however, the airport authority can cover virtually all operations conducted at an airport. In contrast, somewhere else, it can only cover a reasonably limited portion of overall airport activity. Airports' critical infrastructure and services include runways, taxiways, apron space (ramp), passenger terminals, air cargo terminals, and land transport interchange facilities. Airports are power-intensive areas because of the enormous buildings (both passenger terminal and non-passenger zones) fitted with heating and air-conditioning installations, as well as the high-power demand for lighting and electrical equipment and the electricity needs of the many facilities situated in the airport area. In addition to supplying the electricity needed to aid commercial aviation operations — for example, lighting and weather forecasting systems — electricity is also required for airport structures, aircraft hangers, and other airport facilities. Thus, energy management and optimization— including heating, cooling, air-conditioning (HVAC), and lighting — are highly essential for airports.

" According to Akyüz et al. (p. 1849), "70% of the electricity used in airport terminal buildings is used for heating, cooling, and air-conditioning purposes." HVAC energy usage is higher in cold-climate countries". Airports need a reliable, reasonably priced, and robust supply of electricity to satisfy the maximum demand from business partners and passengers and thereby maximize their operating capacity. Maintaining atmospheric temperature and air quality within airport passenger terminals usually constitutes the single most significant contribution to energy consumption and management in most airports (Uysal & Sogut, 2017).

Airport's primary energy needs.

The energy produced by airports can be widely divided further into energy consumed by airports and energy consumed by the guidance organized at the airport by landside areas. The airside is the moving area of the airport, adjacent land, and structures/installations or sections thereof, with restricted access. Landside includes all the places not in the airside zone, including the surrounding land and houses, stairs, duty shops, etc. Energy requirements include the fuel used by aircraft in the airport sector during landing and start-off (LTO) cycles. Electricity is also consumed in land vehicles servicing aircraft in the elaborate apron/gate. Airport landside critical energy consumers are airport ground control systems/modes, passengers and air freight terminals, and other public buildings serving the airport. In all cases, primary energy sources are non-renewable fossil fuels and, to a minimal extent, renewable wind, water, and solar. Airports would need to light parking, train stations (where they are situated at the airport), and access/points to land transfers. The power to operate the airport's systems, equipment, ventilation, and lighting is important for airport stakeholders (Baxter, Srisaeng, & Wild

, 2018).

Energy Use at airport

Airports are small to medium-sized city-like facilities. They, therefore, need the energy to run and deliver their infrastructure. Airport networks have high energy demand due to the unique demands of airport buildings and facilities – such as air conditioning terminals, pre-conditioning air and gates energy, power supply for many airport-specific types of equipment and other services, such as baggage handling and lighting. Airports are centers of regional economic activity and constitute a vital connection in regional networks. The safe, economical, and, above all, reliable electricity supply at airports is therefore of significant importance. Airports of all sizes must provide a minimum service level that includes energy usage to ensure safe and effective flight operation. Airport terminals: electricity, heat up and cooling (air conditioning) and equipment(baggage handling devices, terminal bridges)-Airport airside: Runways lighting, auxiliary power units (APUs) and ground energy aircraft systems (AGES), ground vehicles (from airport support providers, terrestrial and firefighting companies) and airport facilities

An energy audit will help an airport operator recognize its energy usage and is strategic for energy efficiency technology investments. For instance, if heat water boilers are a significant energy source for an airport, trying to replace that system with such a geothermal or solar water heater could become a high priority to reduce running costs. Alternatively, an airport operator may choose to outline energy efficiency steps to be taken (to achieve savings on costs or emissions) and guarantee that airport staff and management work towards each other and endorse these objectives. Once the airport operator understands its energy use and where the best and most economical improvements are available, the airport can impulse purchase in renewable energy projects. (International Civil Aviation Organization, 2019). Principal shareholders and their energy needs at the Landside area of an airport and the Airside area of the airport in the below-given tables, respectively.

Table 4 Key shareholders and their energy needs at the Landside area of an airport (Baxter, Srisaeng, & Wild , 2018)

Stakeholder	Power Requirements for
Airport Authority	Provision of terminal(s) power, terminal and facilities lighting, air conditioning (cooling and heating), car park lighting, power for baggage systems
Airlines	office air conditioning, IT systems, and lighting
Airport Tenants and Concessionaires	office air conditioning, IT systems, and office/terminal lighting
Car Rental Firms	office cooling and heating, IT systems, and vehicle washing facilities
Cargo Terminal Operator	office air conditioning, IT systems, cargo handling, and office/terminal lighting
Forwarders	office air conditioning, IT systems, and office/terminal lighting Government
Eating and Dining Establishments	office and cooking/refrigeration systems, lighting, and air conditioning Freight
Agencies	office air conditioning, IT systems, and lighting
Ground Handling Agents	office air conditioning, IT systems, office/terminal lighting, and electric powered ground service equipment (GSE 2)
Ground Transportation and Parking	office air conditioning and lighting
Hotels	office, guest, and function rooms; air conditioning; lighting; catering and cleaning; and IT systems
Security Services	office air conditioning, lighting, IT systems, and security screening equipment
Taxi Holding Bays	office air conditioning, lighting, signage, catering facilities

Table 5 Key shareholders and their energy requirements at an Airport (Baxter, Srisaeng, & Wild , 2018)

Stakeholder	Power Requirements for
Airport Authority	Provision of the terminal(s), apron, taxiway, and runway lighting, air conditioning, electric power and air to aircraft gates, the power to facilities, ground equipment, maintenance facilities, and baggage systems
Airlines	office air conditioning, IT systems, lighting, and fuel handling systems
Air Traffic Control	office air conditioning, lighting, and ATC systems
Airport Tenants and Concessionaires	office air conditioning, IT systems, and office/terminal lighting
Airport Fuel Farm and Suppliers	office air conditioning, IT systems, and lighting
Aircraft Maintenance Firms	office air conditioning, IT systems, and lighting
Cargo Terminal Operator	office air conditioning, IT systems, cargo handling, and office/terminal lighting
Fixed Base Operator (FBO)	office and cooking/refrigeration systems, lighting, and air conditioning
Flight Catering	office air conditioning, IT systems, and lighting
General Aviation/Business Jet Center	office air conditioning, IT systems, and lighting
Government Agencies	office air conditioning, GSE, IT systems, and lighting
Ground Service Equipment (GSE) Maintenance Firms	office air conditioning, IT systems, and lighting
Ground Handling Agents	office air conditioning, IT systems, office/terminal lighting, and electric powered ground service equipment (GSE 2)

Energy Management (EM) at Airports

Various efforts have been made to reduce the impact of energy costs. In addition to advances in building and construction technology, along with sustainability and fossil fuels, EM has become an essential factor. Sustainable development is achieved, and energy resources are used effectively at airports, however, due to complex, interrelated, and socio-economic problems. Facilities that use renewable energy sources, market growth, and control mechanisms and the application of EM models for the diffusion of low-carbon technology are the key themes discussed in different studies. There is also evidence that work on sustainable EM in airports dealing with relevant issues is on the rise.

However, sustainable EM strategies are still challenging to implement for the industry in the region, let alone for feasible airports. Today, there is still tremendous potential for enhancing airports' energy quality, which can be supported by integrated solutions with a substantial potential to reduce energy consumption between 20 percent and 50%. For instance, Balares et al. have identified a thermal energy potential of 35% in Greek airports. In the Hong Kong Airport, the Sun et al.'s analysis showed 5.93% progress, while in Adelaide, Huang et al. recorded an 18% energy savings. Although energy savings can bring benefits for the aviation and airport industries, they are generally difficult to implement. Many key obstacles include maintaining system security and continuity in transition phases, funding and resource provision, the maintenance of landside operations and services. Furthermore, factors such as CO_2 emissions and irreversibility affect energy efficiency in airports. Therefore, the primary aim of sustainable airports is to minimize CO_2 emissions in the aviation industry, as set out in Fig. 6. Different types of airport EM systems can be suggested (Uysal & Sogut, 2017) Figure 11 shows the flow chart for energy auditing for airports.

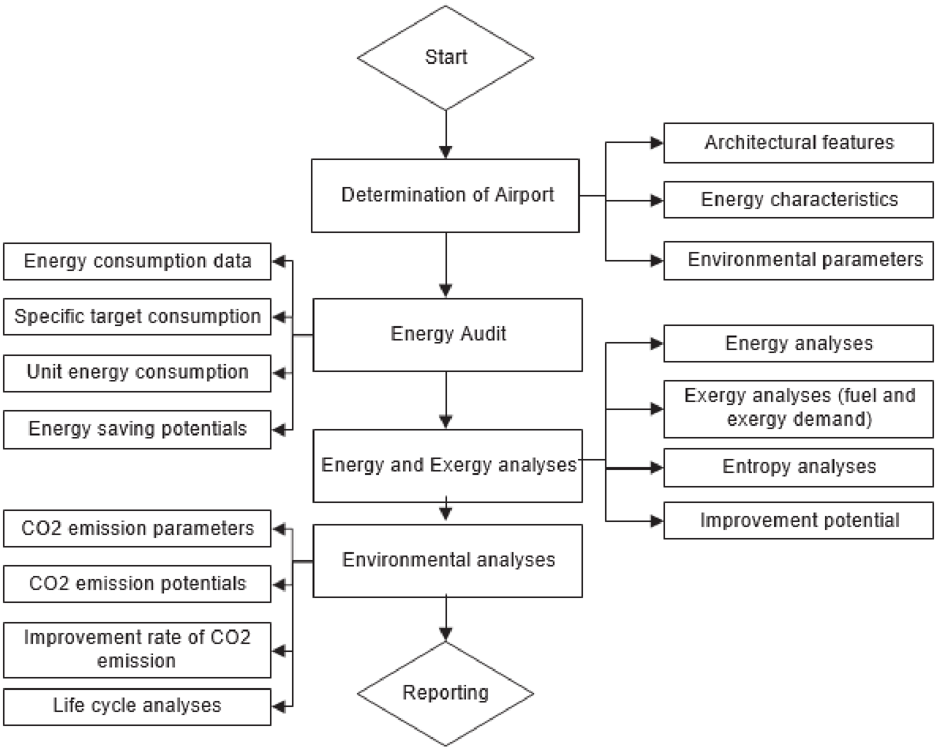

Figure 11 Flow chart for energy auditing for Airports (Uysal & Sogut, 2017)

Energy Mapping

Energy mapping develops on the fundamental concepts of what energy planners are trying to do, includes establishing the energy and greenhouse gas objectives and can connect motives aimed at connecting land usage and form to actionable demand-side management and addressing local energy challenges. Energy mapping promotes identification and decision making in neighborhoods, towns, cities, and regions of diverse energy use and pollution reduction opportunities. It is expected that it will help cross-cutting decision-making, as well as investment decisions. In the airport it is exciting to analyze the energy distribution and consumption (Canadian Urban Institute, 2012) It shows us a clear path to plan for energy efficiency and energy savings in various parts of the building. Energy distribution of Airports by building type and energy consumption by building use, in general, is given below

Table 6 Energy Distribution of Energy consumption at Airport (Ortega Alba & Manana , 2016)

Description	% energy Distribution
Terminal Building	**76.5**
Parking	**2.5**
Fire Fighting Building	**1**
Airfield Lighting	**7**
Radio Navigation systems	**5**
Others	**8**

The terminal building consumes most of the total power supplied to the airport as it uses energy for lighting, airline operator, terminal building lighting, baggage supply, elevators and escalators, lifts, heating and cooling needs, duty-free shops, cafeteria and other equipment used in the terminal. Table 6 shows the energy distribution of energy consumption at the airport.

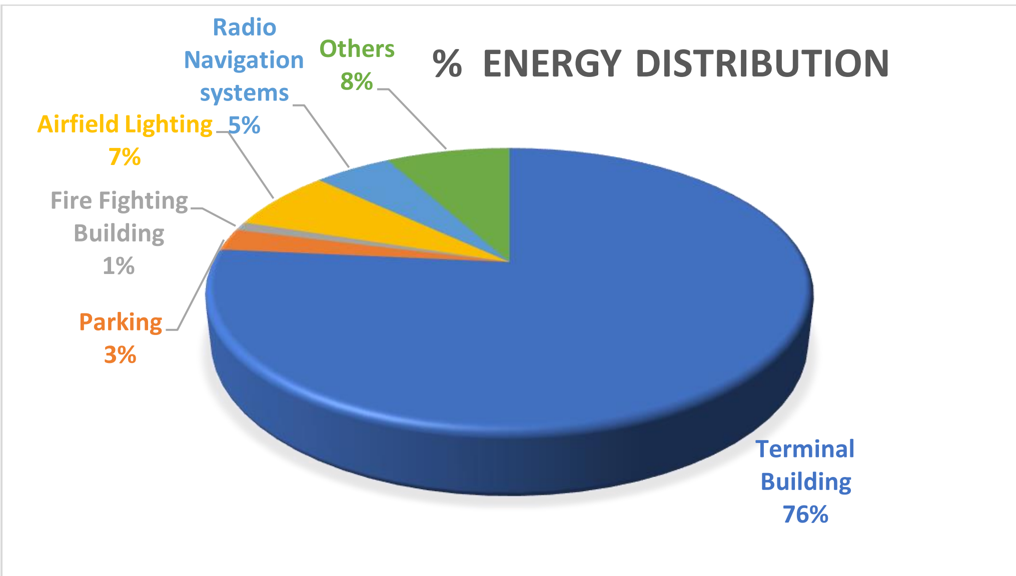

Figure 12 Distribution of energy in various components of the Airport (Uysal & Sogut, 2017)

Table 7 Average Airport energy Consumption by facilities at Airport (Ortega Alba & Manana , 2016)

Description	% energy consumption
HVAC systems	**25**
Lighting	**19**
External Companies	**12**
Information and Communication Technology	**18**
Airfield Lighting	**7**
Radio Navigation	**5**
Electromechanical Facilities	**3**
Others	**11**

Table 7 shows the average airport energy consumption by facilities at the airport. Heating and cooling needs are the most energy-consuming needs, followed by lighting. Other facilities include charging of bus stations, baggage processing, etc.

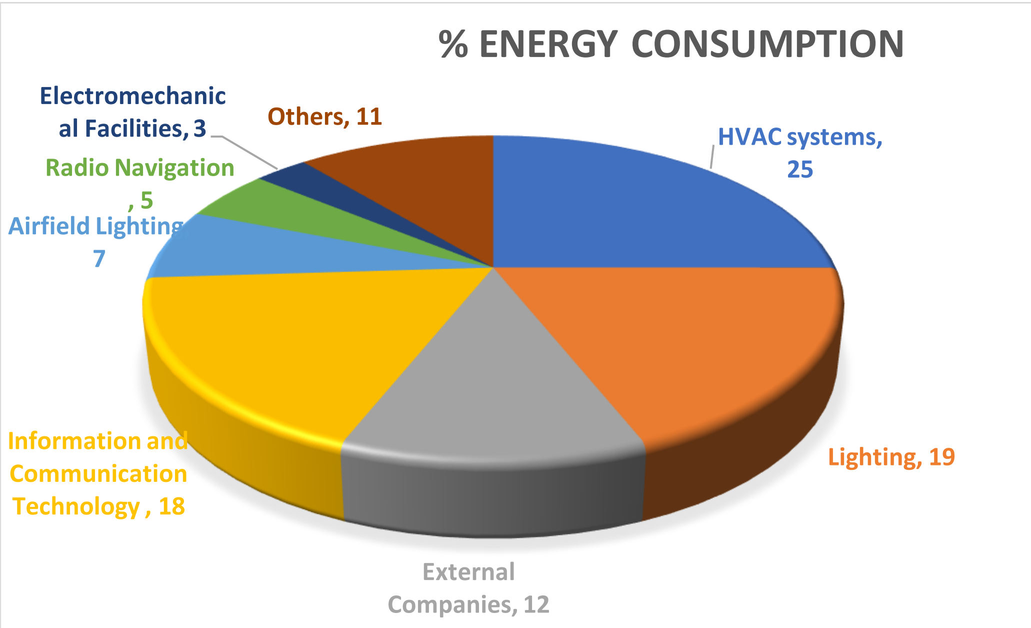

Figure 13 Energy consumption at the airport (Uysal & Sogut, 2017)

Energy calculations

According to (World Meteorological Organization, 2008) , the average monthly sunshine and climate data are given below as follows. Norway, in general, receives less amount of sunlight. But with an exceptional summer, the sunlight will be more than enough to produce the required amount of energy. Winters receive an average of 2.33 hours of sunshine, and summer receives around 6.08 hours of sunshine. Monthly data shows, December receives the lowest sunshine, and June receives more sunlight. Table 8 shows the average sunshine data for the whole year, along with daylight hours and UV index.

Table 8 Average Daylight\sunshine hours in Stavanger (Weather Atlas, 2020).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Daylight (h)	7.1	9.3	11.9	14.5	17	18.4	17.6	15.4	12.8	10.2	7.7	6.3
Average sunshine (h)	1.5	2.8	4.5	5.6	7.3	7.4	6.4	5.1	4.7	2.6	1.5	1.1
UV Index	0	1	2	3	4	5	5	4	3	1	0	0

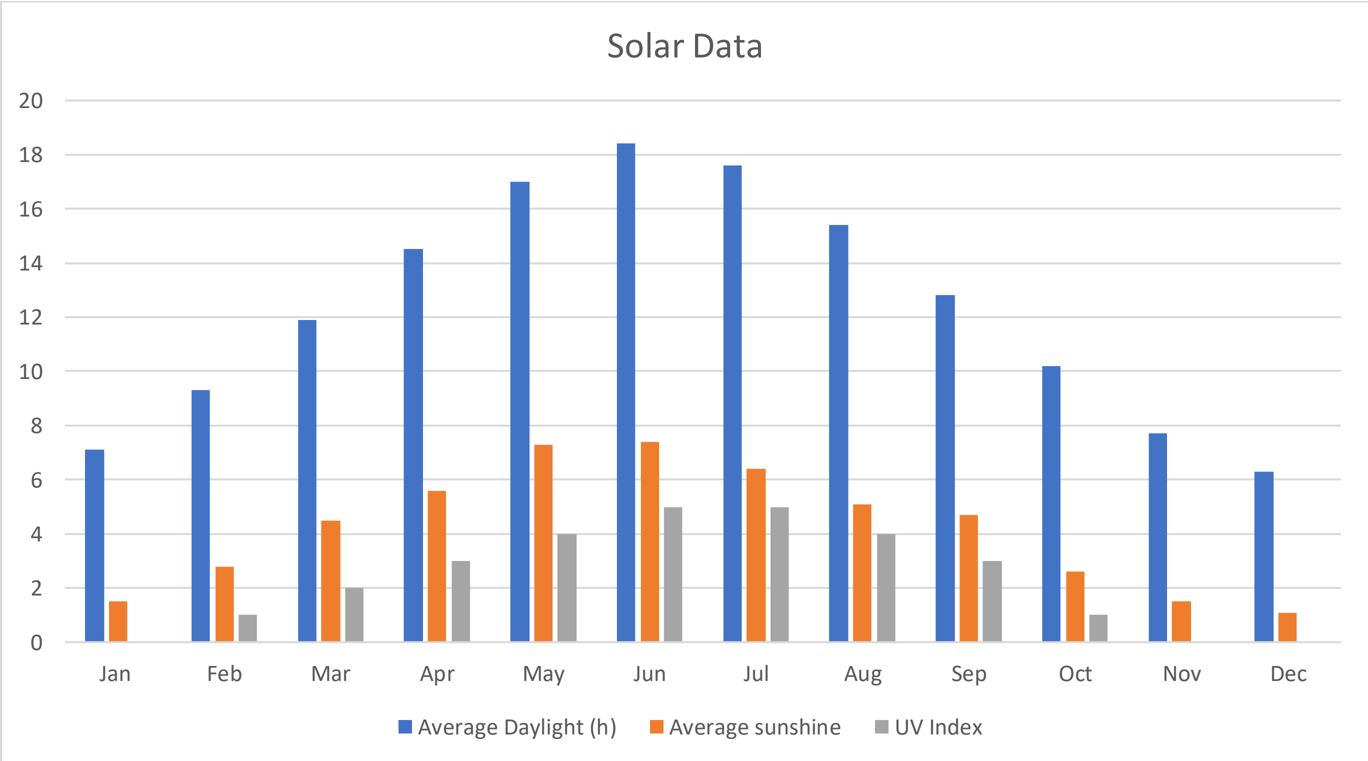

Figure 13 Avg Sun Hours Vs. Sunshine Vs. UV Index (Weather Atlas, 2020)

Existing Energy production from the different modules

In the current year, the ten mono-crystalline panels generated a total of 2127 KWh. A total of 2042 KWh were produced in the ten polycrystalline panels in question during the year. Given that mono-crystalline panels are higher in power (285 Wp) than polycrystalline panels (265 Wp), actual annual results from panels are to be contrasted. In the current year, the ten mono-crystalline panels had such an outstanding output of 746 KWh / KWp. The ten polycrystalline panels in question had collective energy of 771 KWh / KWp this year. (Avinor AS, 2018).

Table 9 Average energy production and specific performance vary for different orientations and angles (Avinor AS, 2018).

Average annual production per panel [KWh]		
Orientation	**MonoSol 285**	**PolySol 265**
South	**237**	**233**
South-East	**225**	**196**
South-west	**222**	**213**
East	**192**	**188**
Vest	**187**	**190**

.*Table 10 Overview of average specific performance from the different panel types, orientation, and angle (Avinor AS, 2018)*

Specific performance [KWh/KWp]		
Orientation	**MonoSol 285**	**PolySol 265**
South	**830**	**881**
South-East	**791**	**740**
South-west	**779**	**803**
East	**675**	**711**
Vest	**657**	**718**

Performance from solar panels

The average specific outcome of the ten mono-crystalline panels was projected at 836 KWh / KWp through a simulation. The value calculated was 11% lower. The average specific performance of the ten polycrystalline panels was projected at 819 KWh / KWp through simulation. Measured performance was 6 % lower. A comparison of approximate and calculated performance for various panel styles, orientation, and angles are given in Table 11 (Avinor AS, 2018)

Table 11 Comparison of estimated and measured specific performance for different panel types, orientation, and angle (Avinor AS, 2018)

Specific performance [KWh/KWp]			
Orientation Panel Type	Goal	Simulated	**Difference**
South, M	**830**	**883**	**−6%**
South-East, M	**791**	**844**	**−6%**
South West, M	**779**	**867**	**−10%**
East, M	**675**	**781**	**−14%**
West, M	**657**	**804**	**−18%**
South, P	**881**	**866**	**2%**

South-East, P	**740**	**828**	**−11%**
South West, P	**803**	**849**	**−5%**
East, P	**711**	**765**	**−7%**
Vest, P	**718**	**787**	**−9%**

It is reported that the polycrystalline panels provide better efficiency than the mono-crystalline panels. The 10 degrees East-West installation provided 19-20% less output per panel than the 15 degrees South Facing installation. The PVSOL simulation provided a better first result than polycrystalline for the mono-crystalline plates. The measurement data did not suit.

Total energy consumption at Sola Airport

Table 12 shows the weekly electricity consumption of energy at sola airport. The district heating and direct electricity consumption at the Airport for the year 2019."Direct electricity" is the power delivered directly from Lyse. In the buildings, they have a waterborne heating system, and the “district heating" is produced from Norsk Bioenergi. Energy for District Heating is provided from the nearby wood-burning plant. The readings are observed from TIGO, which is being installed at the airport.

Table 12 Weekly Electricity consumption of Sola Airport (observed Data from TIGO)

Week	Direct el 2019 [KWh]	District Heating 2019 [KWh]
1	320,772	73,758
2	334,115	85,372
3	354,529	122,300
4	377,473	127,686
5	376,436	93,734
6	323,747	65,677
7	303,635	76,972
8	300,272	62,241
9	301,943	72,843
10	313,769	77,130
11	307,182	73,085
12	298,103	55,614
13	288,086	56,315
14	276,089	43,286
15	288,114	67,214

16	254,015	34,130
17	255,012	33,515
18	263,260	55,085
19	270,194	38,214
20	252,607	27,643
21	262,315	26,328
22	256,539	13,959
23	256,903	18,370
24	261,616	21,473
25	261,597	22,013
26	258,346	16,358
27	254,688	20,556
28	251,347	15,143
29	258,981	15,328
30	291,040	8,044
31	266,306	10,313
32	270,963	12,043
33	265,266	14,886
34	281,690	14,928
35	285,273	9,656
36	272,759	16,443
37	278,189	16,372
38	273,007	21,014
39	275,059	18,657
40	286,645	26,657
41	278,970	33,429
42	281,673	36,643
43	286,967	40,928
44	296,311	48,314
45	313,152	77,558
46	308,313	77,385
47	303,451	64,829
48	310,483	71,443

49	307,536	65,095
50	319,148	74,781
51	309,589	68,259
52	299,004	68,259
Total	**15,042,479**	**2,407,278**

So the actual total energy consumption at the airport for the year 2019 is calculated as the sum of direct electricity and electricity needed for district heating, which is 17,449,757 KWh in total. But the electricity from solar panels will only be utilized for electricity needs and not heating needs (as planned by Avinor).

Energy Vs. Cost

Table 13. displays the energy usage (purchased power) trends at the airport, related data, and energy cost in 2012, 2018, and 2019. The green circle shows a decrease in the table. To take account of land changes in that period, energy performance as measured on changes in the specific energy consumption (KWh / m2).

Table 13 Energy Vs. Cost (Avinor AS, 2019)

Description	Reference			Change	
	2012	2018	2019	2012-19	2018-19
Area [m2] Energy cost [Kr]	**49,872** **9,820,000**	**60,945** **12,680,000**	**60,945** **10,800,000**	**22%** **10%**	**0%** **-15%**
				%	**%**
Power [KWh]	**18 006 148**	**16 432 534**	**15 199 372**	**-16 %**	**-8 %**
Oil/gas [KWh]					
District heating [KWh]	**2 215 866**	**3 088 241**	**2 459 040**	**11 %**	**-20 %**
Consumption [KWh]	**20 222 014**	**19 520 775**	**17 658 412**	**-13 %**	**-10 %**
Consumption [KWh/m2]	**405**	**320**	**290**	**-29 %**	**-10 %**

The study shows trends in airport energy use, related primary data, and energy costs in 2012, 2018, and 2019. The green circle in the table indicates a decline. The production of energy is calculated in terms of changes in real energy consumption (KWh / m2) (Avinor AS, 2019). Choose the lowest yield during the day, say earlier in the morning and afternoon. In the ideal, usually, cloudless condition. Then measure the surface area on this basis. The extra highest power you receive during the midday is your storage boost, which can be used to increase the usable electricity during the day (Nordic Network for Electric Aviation (NEA), 2020).

Energy potential in Sola Airport

Energy potential is calculated using PVGIS software. The main aim of calculating solar energy potential is to understand the maximum output that can be obtained from the sola airport at an optimum angle and azimuth. These calculations were already being done by Avinor AS. Scenarios are based on different considerations like the location of the site, solar radiation, Radiation Angle, and climatic conditions. For example, At the equator, the optimum angle of inclination will probably not the same as in the Nordic regions. It is subjected to vary depending upon specific site conditions. So it is necessary to make different scenarios using the trial and error method to find the best suitable energy scenario that could be adopted in this particular site. Three different scenarios are considered where the angle of inclination considered is 45 degrees, 20 degrees, and 10 degrees. The direction of panels is of south-oriented in the first two scenarios, whereas the third scenario is oriented towards east\west. The total potential at the airport is given below.

Table 14 Total Potential at Airport (Fadnes, 2016).

Description	East/west-facing solution	South facing solution
Installed capacity [MWp]	16,8	**11,4**
Energy production [MWh/year]	**14 900**	**10 400**

SIMULATIONS

In the analysis, the climate data co-ordinates used is 58.87 ° N11/5.62 ° E, which is obtained from PV GIS. Simulations are done using PV GIS and PV Syst and are compared. Losses considered are due to cloud shading and due to the difference in actual reading at the site.

Sun Path Diagram

Solar altitude and solar azimuth can be directly measured from solar projections or sun route charts for any date of the year and any hour of the day. There are many simulation methods to reflect the sun's apparent two-dimensional motion, but the "stereographic" method mentioned here is commonly used

Imagine covering every point on the Earth's surface by a hypothetical hemisphere. Every point on the surface of the hemisphere is connected to the sphere's low point-similar to seeing the inside surface of the upper hemisphere from the low point as the location of the eyes. These connecting or sightlines cut the sphere 's equatorial axis; this plane can reflect the horizon.

On this plane, at the intersection of sightlines, each point on the surface of the hemisphere can be interpreted. The sun's paths can be plotted on such a projection as they tend to travel through the imagined sky hemisphere; the altitudes can be represented by a series of clustered spheres and the azimuths by a range from 0° to 180° throughout the periphery. The altitude and azimuth of the sun can, therefore, be read directly at any time. Every such diagram is right for one Latitude; each such diagram will, by reversing the date, represent the corresponding Latitude in the other hemisphere as well. The sun path diagrams even plot hour lines. Both these times are in real solar time; at noon, the Sun is due south (in the northern hemisphere). It can be shown that equinox sun paths reveal sunrise precisely due east and sunset due west at 6:00 and 18:00, respectively (Sun Path Diagrams, 2020).

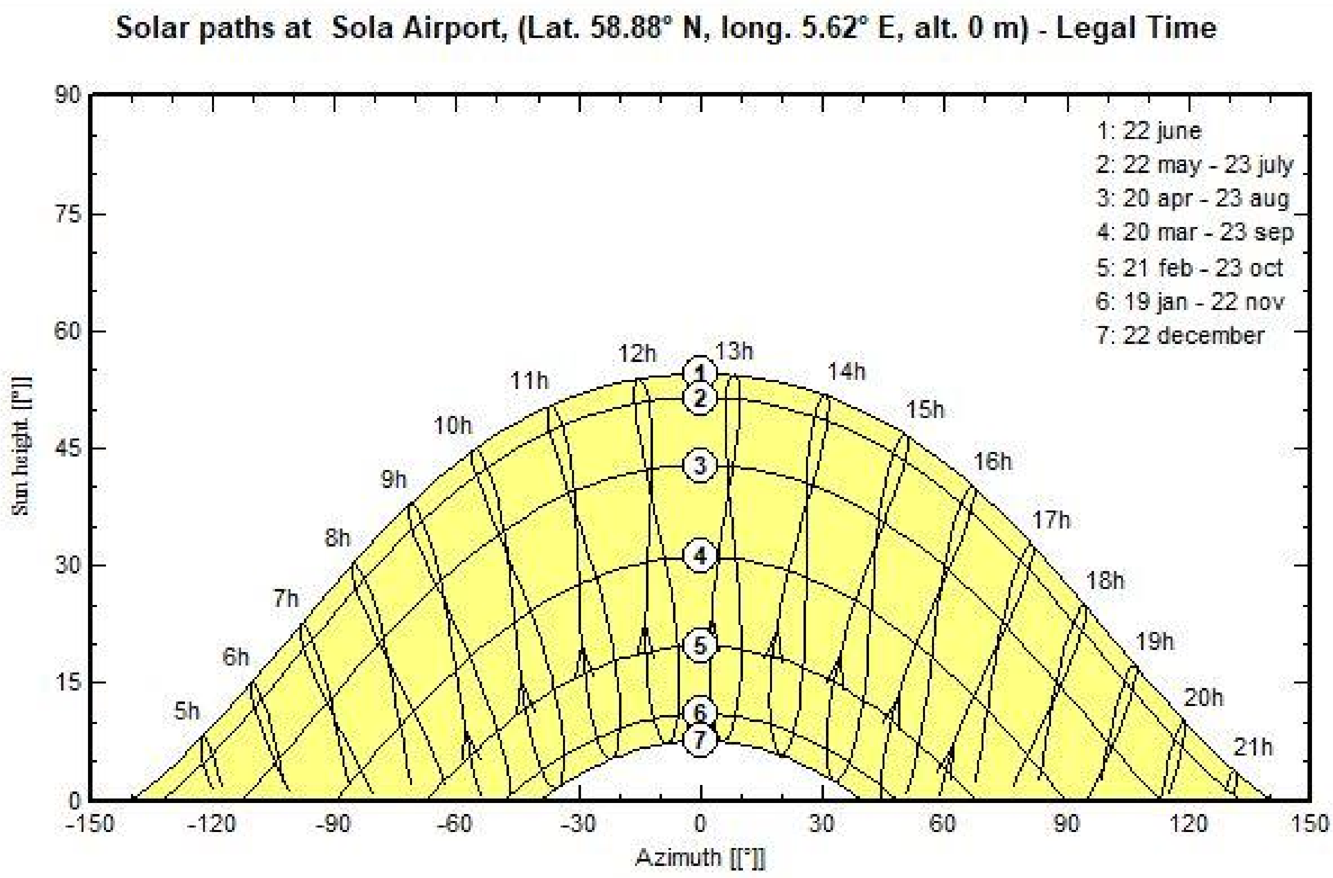

Figure 14 Solar Path at Sola Airport (PV Syst)

The solar path diagram shows the sun path at sola airport throughout the year. It is highest in summer and lowest in the winter. The sunniest day and sun path is the highest being on June 22. There are seven different timelines given in the diagram, which can be adjusted accordingly to get the required data all year at any point in time. Shading has a vital role in the performance of a solar photovoltaic system, and sadly many system designers don't take shading into account when analyzing system performance. Some applications, like PVsyst, can simulate shading and estimate energy losses due to the PV array shading. Below is a typical Sola Airport's sun path. Besides, the first-ever prerequisite is to consider the sun path diagram of a specific location showing the sun path through the sky from summer to winter solstice. PVsyst is capable of producing sun track diagrams for a defined location, and power output can be calculated for each hour in the winter and summer seasons, thereby optimizing the device configuration for annual production, summer yield, or winter yield depending on design criteria. It is even possible to quantify the reductions in energy production of a solar plant due to shading from an individual entity. Here the shading losses are different for a different type of scenario considered. As it is an open site that is considered for solar plant installation, here, the shading losses is very minimal (Muthyal , 2013).

Scenario 1 (Inclination angle 45° Azimuth angle 0°)

The angle of inclination and azimuth considered in Scenario 1 is equivalent to the placement and positioning of Solar panels at Stavanger Airport placed for testing. Solar modules are placed south-facing. The horizontal plane angle is 45 °. It is usually considered the "optimum" angle and position for optimal final output throughout the year. The drawback is that the system needs a massive distance between panel rows, so they don't shade each other to give optimum output. The solar modules are also subjected to climatic conditions and wind with a large inclination in the interaction with the horizontal axis (Fadnes, 2016).

Figure 15 Solar Panels at Stavanger Airport ((Avinor AS, 2019)) as in Scenario 1.

The result from PV GIS

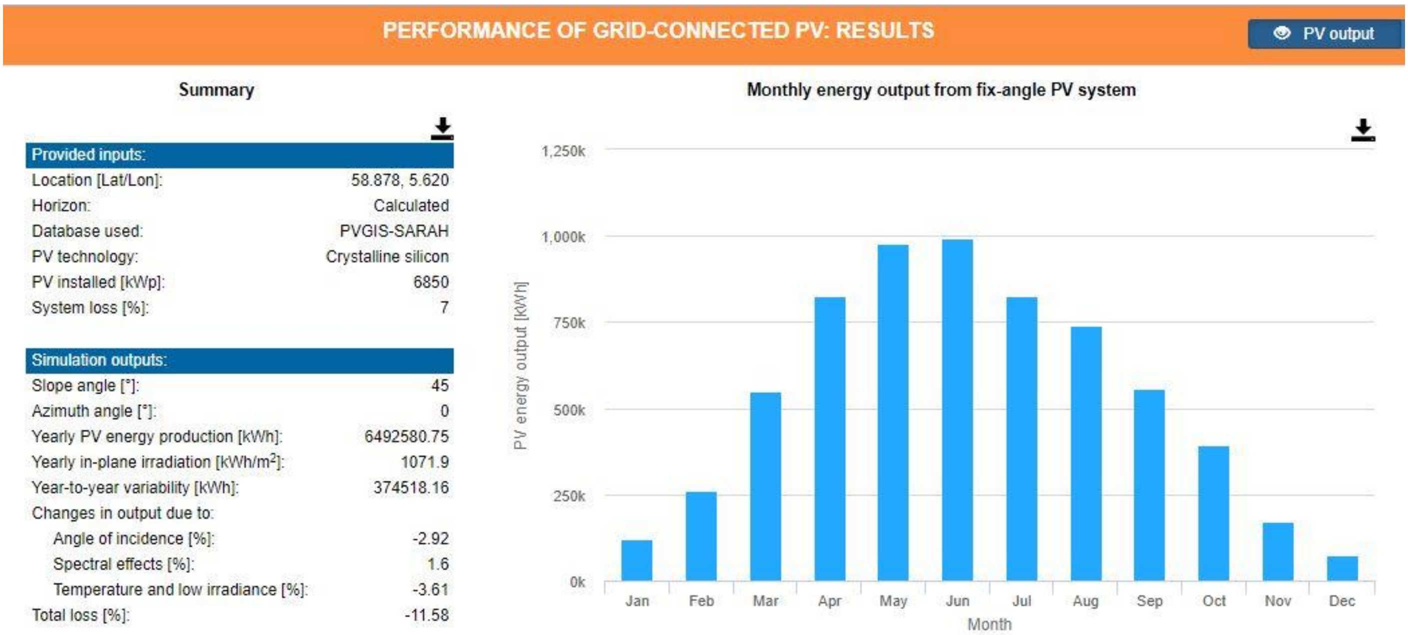

Figure 16 Result for Scenario 1 from PV GIS

The result from PV Syst

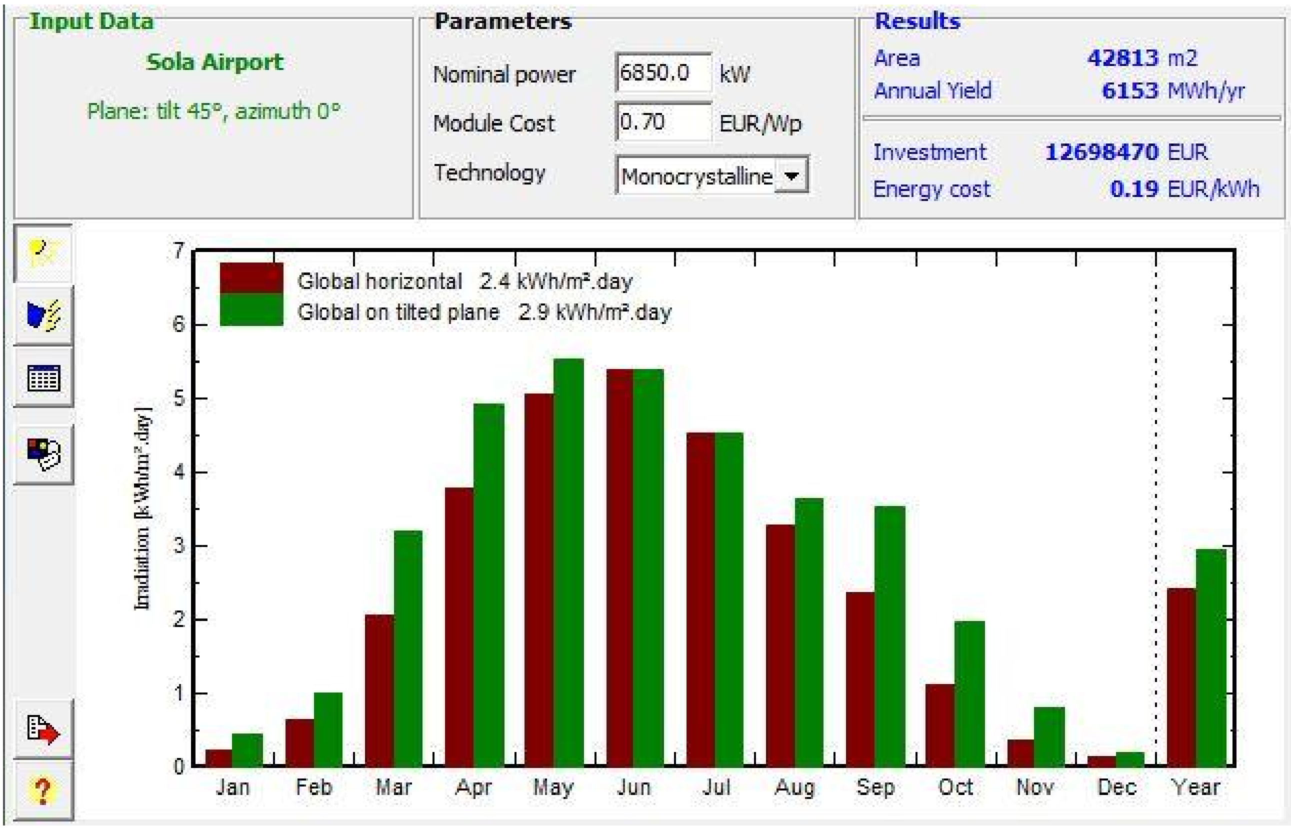

Figure 17 Simulation for Scenario 1 from PV Syst

Scenario 2 (Inclination angle 20° Azimuth angle 0°)

Solar panels are positioned southwards. The horizontal surface angle to the panel inclination is 20 °. The scenario provides less space between the panel lines and is not as vulnerable to external loads as in scenario 1. There is space for more solar panels within the given area, and there is less space in between panel rows, thus estimating total output to be higher than in scenario 1. Relevant (KWh / KWp) output is much lower than it is on the inclination 45° (Fadnes, 2016).

Figure 18 Solar Panel Inclination of 20 degrees at a solar power plant (google image)

The result from PV GIS

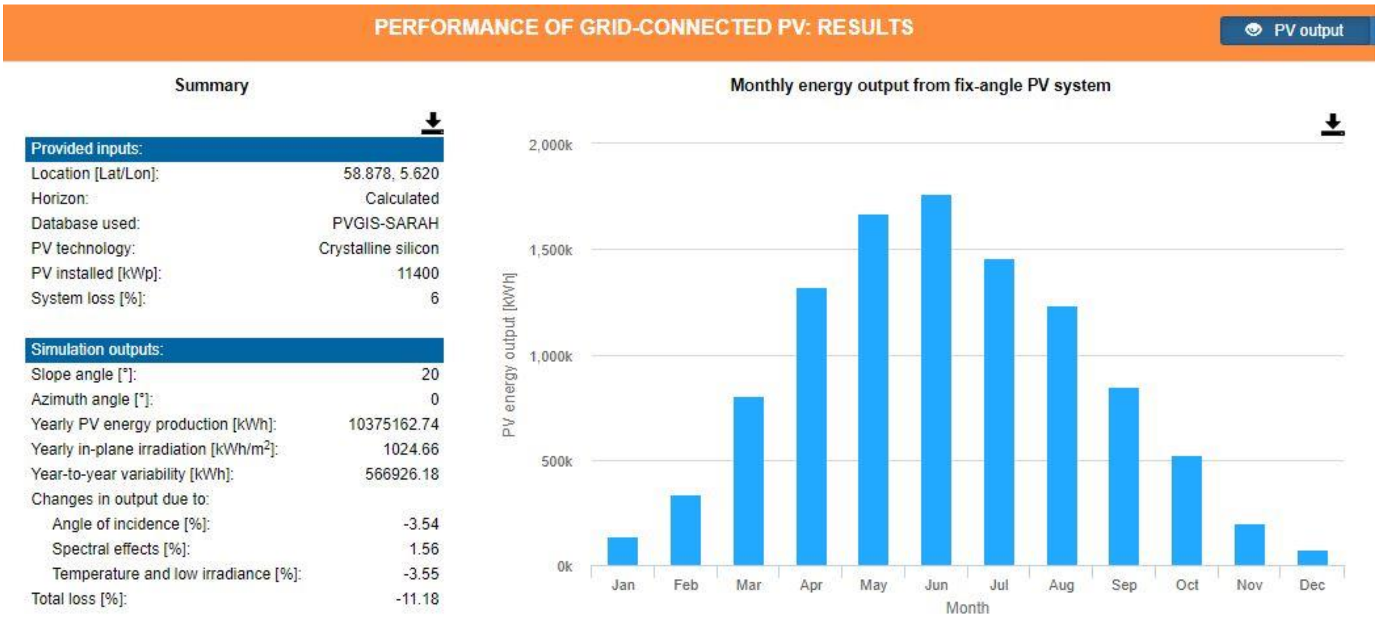

Figure 19 Simulation for Scenario 2 from PV GIS

The result from PV Syst

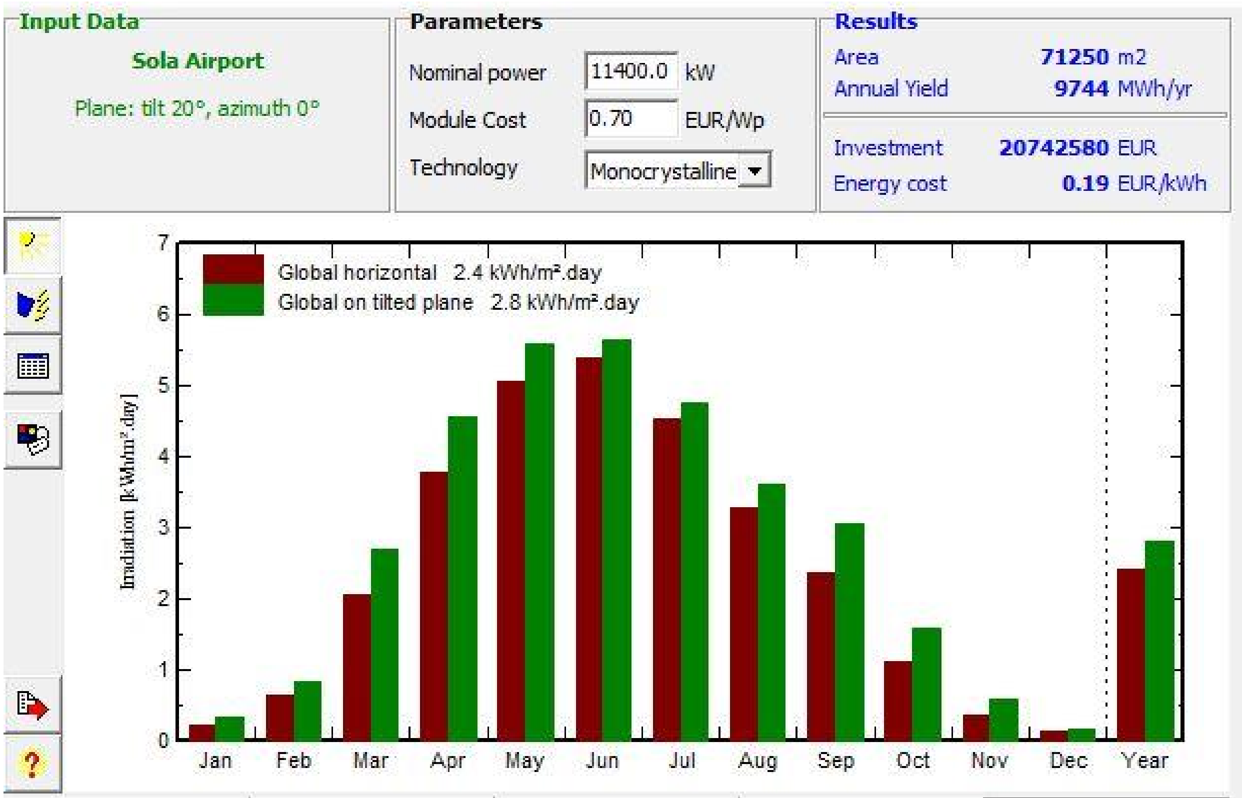

Figure 20 Simulation for Scenario 2 from PV Syst

Scenario 3 (Inclination angle 10° Azimuth angle +/- 90°)

Solar modules are positioned in a 10 ° tilt east / west setup concerning the horizontal axis. It is the most energy-efficient facility, as the solar arrays do not shade one another, in the fact that many more modules can be mounted on the field. Significantly higher output is therefore anticipated, even though specific output (KWh / KWp) is assumed to be lower. A gap of 1.75 m has been placed in between solar panels during the simulations so that a UTV can run between the rows (Fadnes, 2016).

Figure 21 East-west mounting at 10 degrees inclination (Google Images)

The result from PV GIS

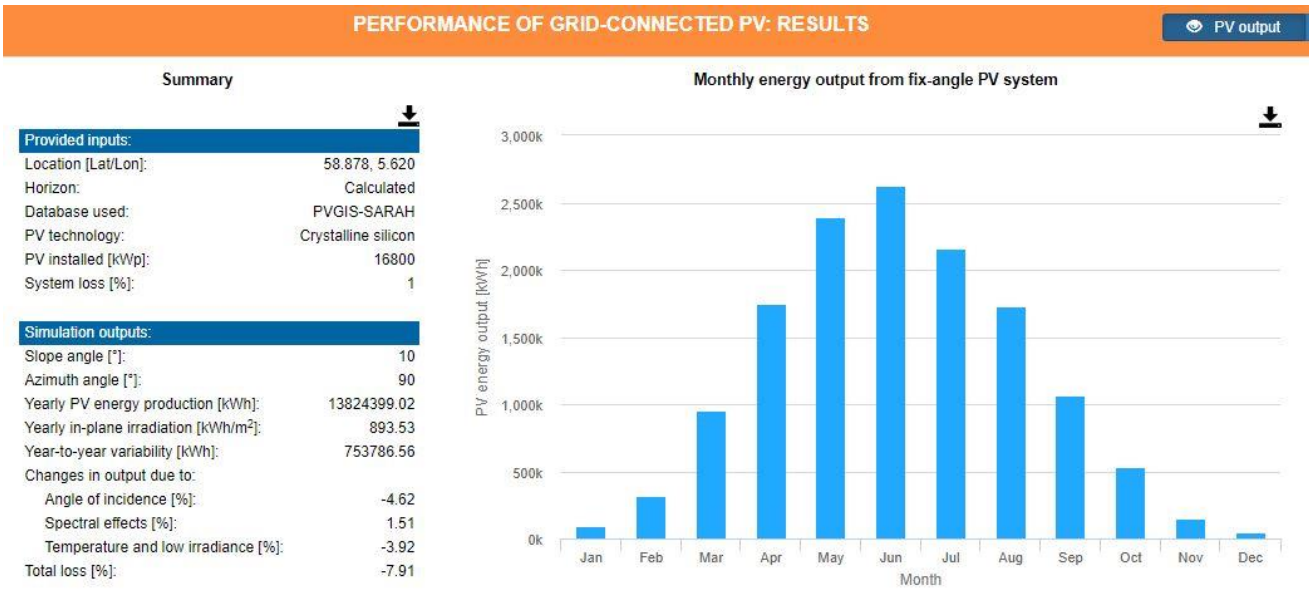

Figure 22 Simulation for Scenario 3 from PV GIS

The result from PV Syst

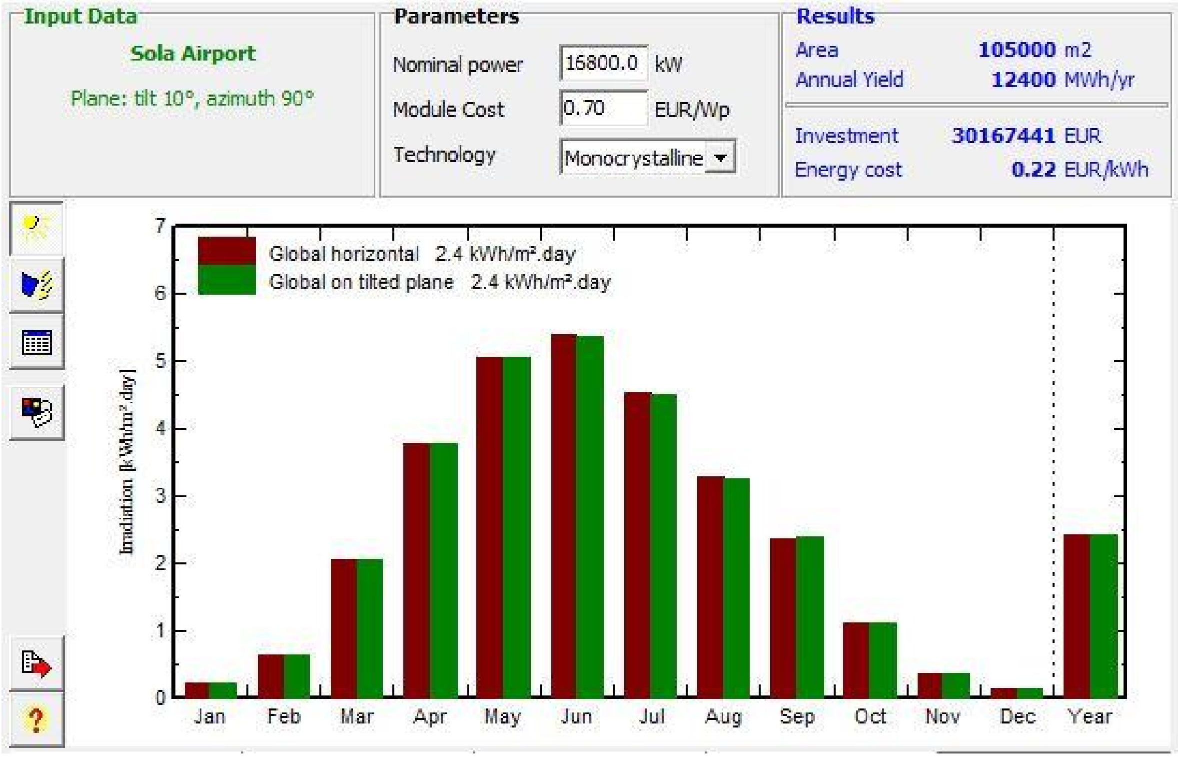

Figure 23 Simulation for Scenario 3 from PV Syst

In the three separate scenarios, solar modules are placed to ensure optimal use of the area that is available. Notice that energy output can not be correlated explicitly in such situations, as the number of panels for each case varies. The effect of the Levelized Cost of Energy (LCOE) measurement, however, will reflect the difference between the approaches. For scenario 1, there is a gap of 6 m between rows with PV modules and 3 m in scenario 2. It provides ample maintenance space between the panel rows (Fadnes, 2016).

Power Flow Diagram

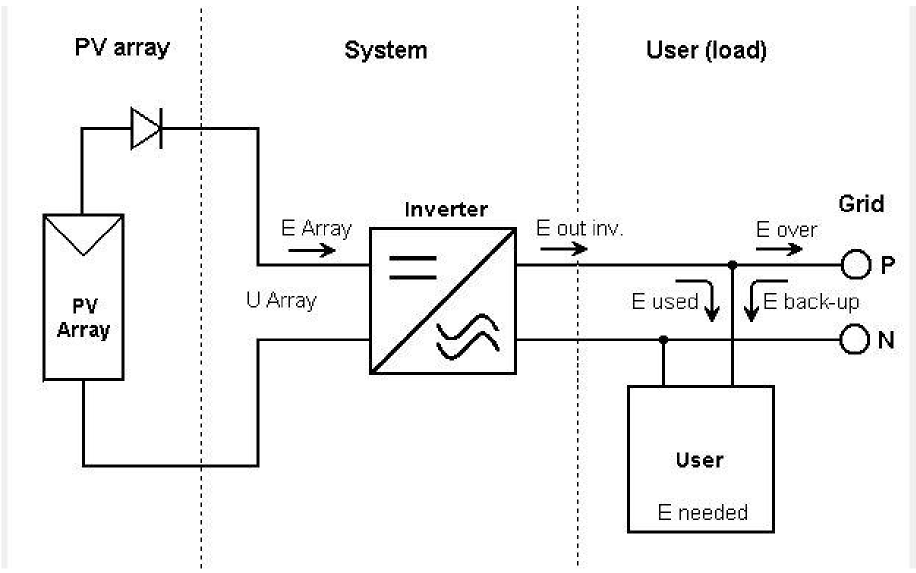

Figure 24 Energy Flow Diagram (PV Sol)

Figure 26 illustrates the energy flow diagram that is being planned for Sola Airport. The energy that is produced in the solar panels or PV array is transferred to a battery where the energy gets stored as Direct Current(DC). When the power is needed for airport consumption, DC is converted to Alternative Current using an inverter. Due to its high efficiency and less wastage, the energy is saved as DC. The energy that is produced more than the requirement can be either stored in the battery, and the surplus can be sold to the grid. As per today's tariff, it might not be advisable to sell it to the grid because of the fewer returns for solar power from the grid. But in the future, it is predicted that the tariffs for solar produced electricity shall be higher, and the returns shall be more than what we get today. When electricity is needed and is in high demand in winter, the energy shall be harvested from the grid. The Levelized cost of electricity (LCOE) for solar PV is already competitive now compared to all fossil fuel generation sources and would be fully competitive in a few years.

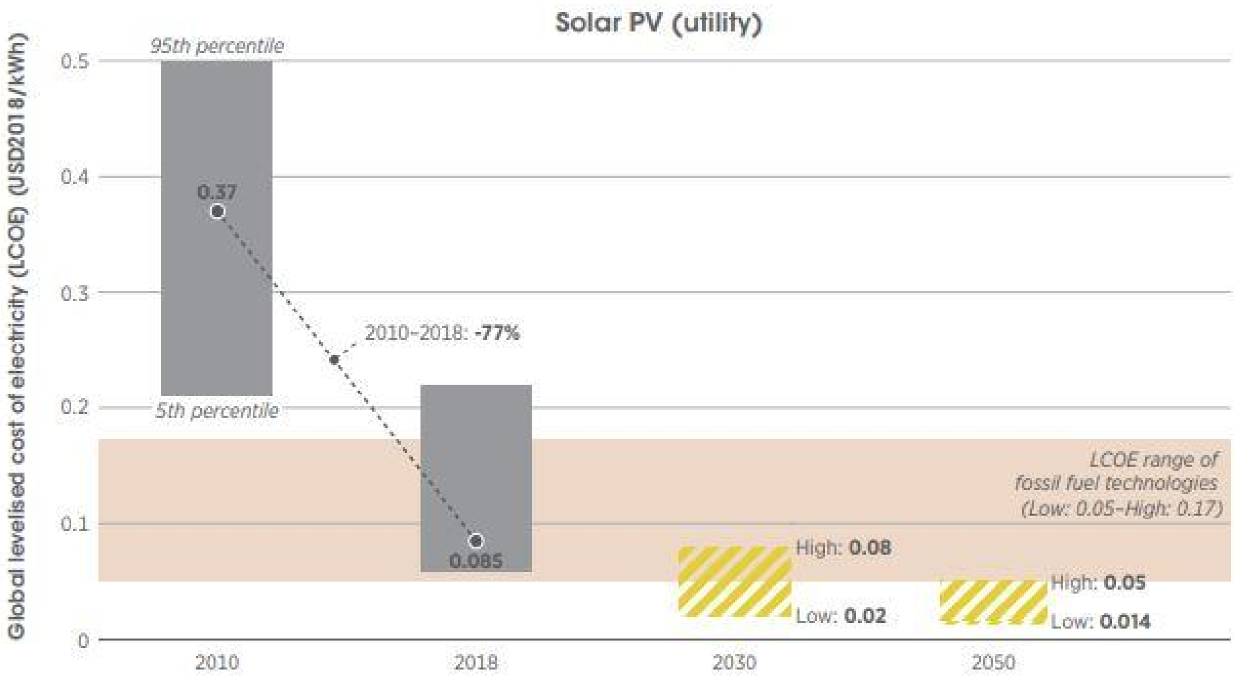

Figure 25 LCOE predictions (IRENA, 2019)

Energy Forecasting

It is quite essential to forecast energy consumption in today's energy consumption. It gives us a precise estimate of the amount of energy that is required for the functioning of the Airport and its future needs. Table 15 below shows the energy forecasting (comparison of current energy needs and future energy demands of Sola Airport).

Table 15 Energy Forecasting (Fadnes, 2019)

Year	Description	Power requirements [KW]	Energy needs [GWh/year]
2018	Today scenario	**3 000**	**16**
2025	Before electrification of aviation.	**2 300**	**14**
2030	After the introduction to electric aircraft.	**12 500**	**25**

Energy requirement for the year 2025 and 2030 is compared with the energy consumption for the current need at the airport. Energy calculation for today's scenario is based on measured readings from the main gauge 7270. For the forecast of 2025, we consider today's need along with increased demand from electric buses (300 KW) and neglecting the energy saving from energy management/smart management/measures (1000 KW). From a long-term perspective, the forecast for the year 2030 is based on the installation of five bridges designed for experimental electric aircraft. (Stavanger – Bergen) (Fadnes, 2019).

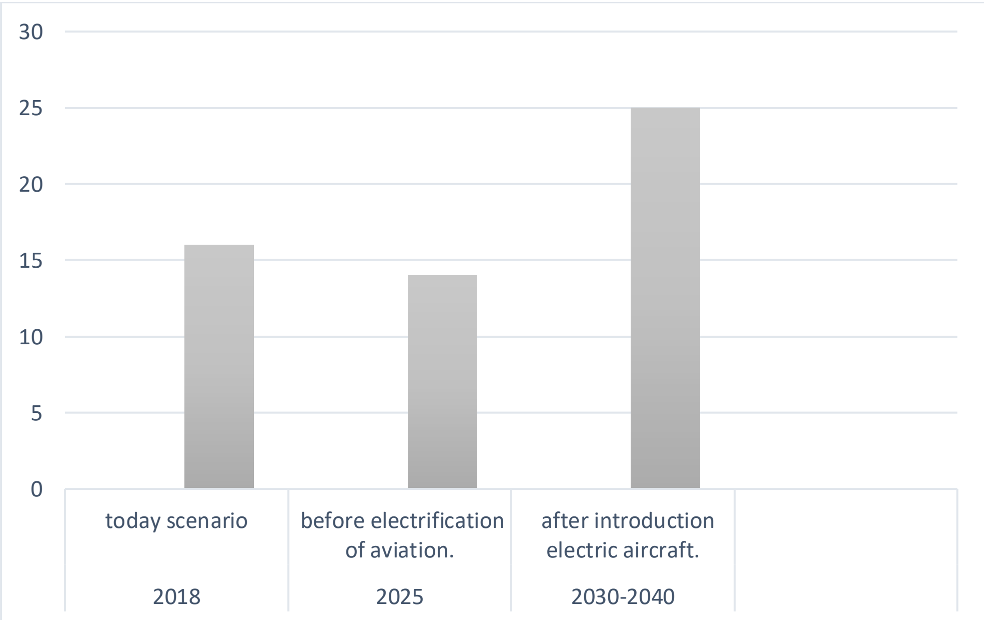

Figure 26 Summary energy and power needs, Stavanger Airport (Fadnes, 2019)

Storage Possibilities

Batteries are recommended included in the concept, and with the growing focus on research and development on the battery technology front, this is expected to be a significantly more mature technology in 2025 and 2040. Although several batteries today are commercially available, however, they are expensive in terms of storage capacity, which holds the technology back for large-scale storage. An energy concept at Stavanger Airport Sola depends on the utilization of battery technology. Due to the maturity of technology, it is expected that this is the technology that is primarily installed late in concept development. The exception is compensation for emergency power generators in case of the low-sight procedure. The battery must be seen in conjunction with both energy needs and energy production facilities and project-specific energy storage needs, as well as cost and profitability considerations in the concept report and are therefore presented in the concept report. The following principles are based on the design of battery solutions:

- Step 1: Batteries are installed to phase out diesel generators in case of the low-sight procedure. The batteries are allowed used for power leveling ("peak-shaving").
- Step 2: The batteries' capacity is assessed based on the size of installed energy production facilities, and energy in demand on the day production is highest. The battery is removed from meeting the 24-hour requirement in combination with the energy production plant. It means that the cells can be used for storing surplus production every day, as well as peak-shaving and storing energy by lave energy tariffs and use/sales at high taxes. These batteries can also act as a back-up for the central system.
- Step 3: In a future solution with electric aviation, batteries are considered an essential piece in the energy system. It is assumed that the battery technologies have had a significant development towards both 2025 and 2040, but it is difficult to estimate costs/capacities and sizes (Hjellbrekke, 2018).

Solar Plus Battery Storage

Most solar-energy device firms are looking at an opportunity to connect the device to a rechargeable battery so they can use it at night or in case of power failure. After all, a solar-plus-storage device is a battery system powered by a linked solar panel, such as a Pv array. (Energy.Gov, 2019).

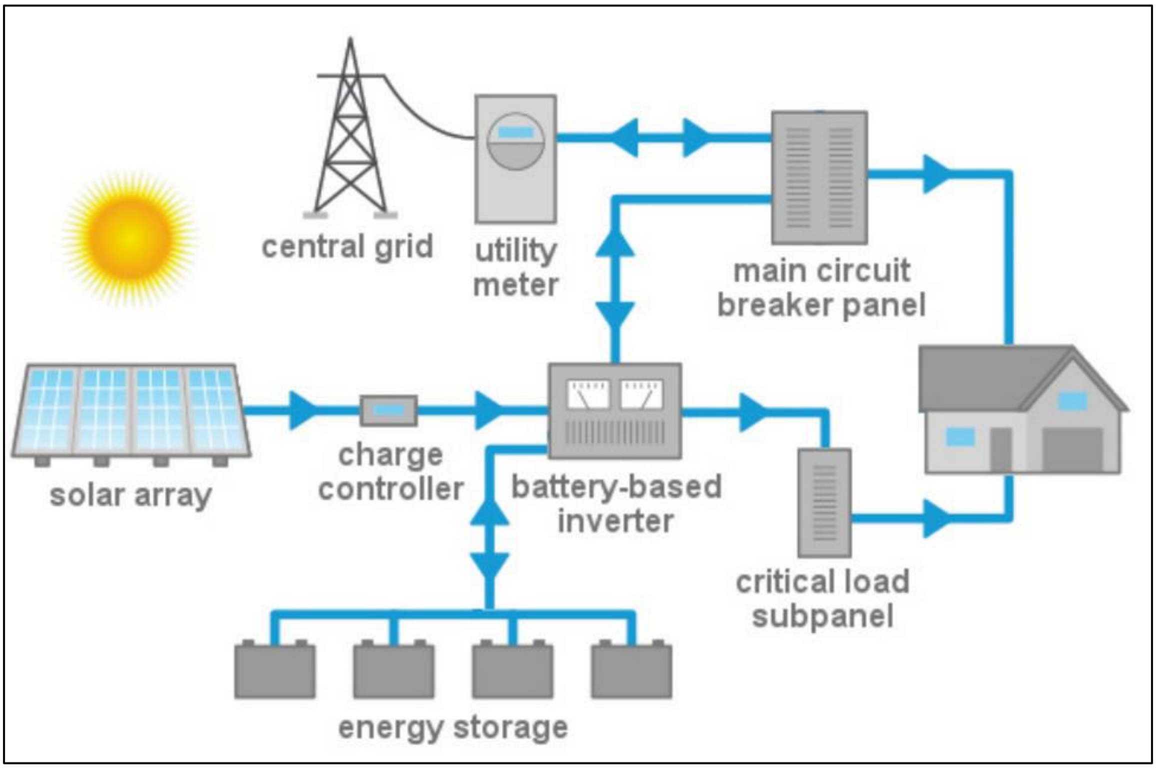

Figure 27 Solar Plus Storage System (Gendler, 2018)

The scenario for Battery Storage

An MWh is the term used to quantify how much energy a battery can carry in an hour. Taking a 240 MWh lithium-ion battery with a peak output of 60 MW. Now imagine the battery is a lake that can be released to generate electricity. A 60 MW storage system could operate in a variety of ways (Energy.Gov, 2019).

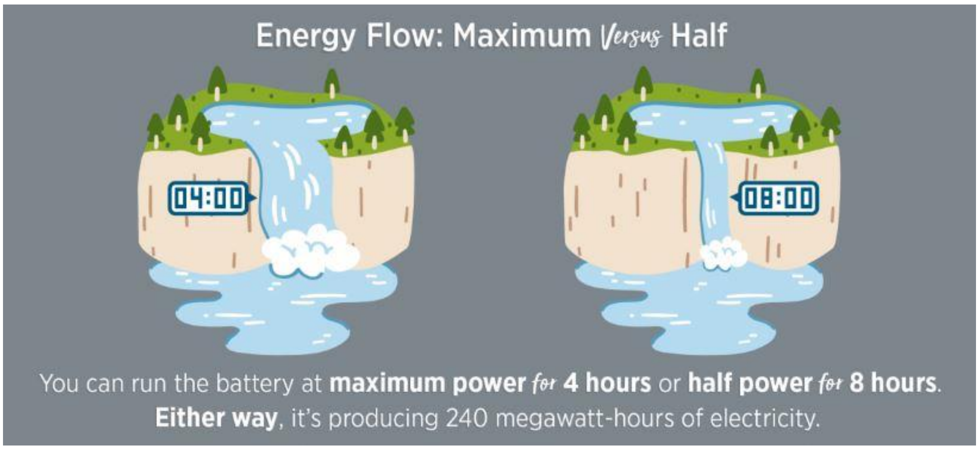

Figure 28 Energy Flow for different time duration and power output (Energy.Gov, 2019).

Within a shorter period, you can get a tremendous amount of power and less amount of power for a longer span. A 240 MWh battery may power 30 MW over 8 hours, but it may not get 60 MW instantly, depending on its MW capacity. It is the reason; the batteries are defined both by power capacity and storage time.

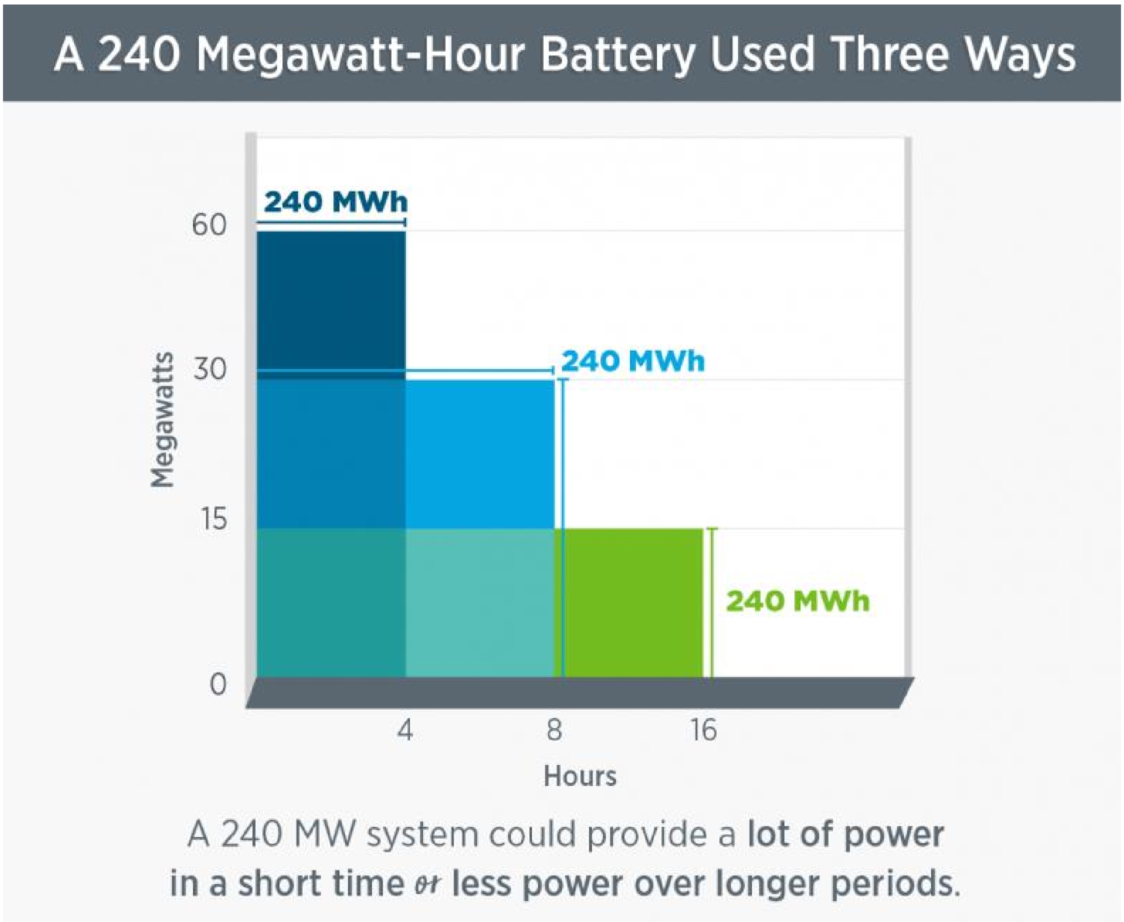

Figure 29 Ways of Battery storage (Energy.Gov, 2019).

Small Batteries

Battery pack for energy storage – with the power of 2 MW or 30 minutes, is being planned to get installed at the Airport. In the low-sight operation, the battery pack should be used for power smoothing and stability, but also as a back-up. Stavanger Airport is among the few airports which can commence a low-term operation, i.e., allow airplanes once visibility is troublesome, e.g., fog conditions. This method includes full redundancy for power supplies for necessary equipment to land aircraft under low-light conditions, such as Airfield lighting. The low-term treatment should be done for two to three weeks over a long time. The necessary equipment today is supplied for reduced visibility is by dual 1100 kVA diesel-powered systems. It acts as a back-up. The diesel systems may be supplemented by a battery pack. A measure that reduces the emissions of 50 to 100 tons of Carbon dioxide per year from the airport's greenhouse gas, as well as battery packs for power leveling which contributes towards this sustainability (ENOVA, 2019).

Safety Considerations

Risk Mitigation assessments should be carried out before the deployment of the renewable energy source, and operational effects should be measured. For, e.g., "the Dutch Airline Pilots Association (ALPA) promotes the use of renewable energy sources as they fit operationally. However, they recommend that the design and engineering will also be accompanied by a risk study unique to each installation." The British 'Honorable Company of Air Pilots' has released practical information for pilots on the health of airports concerning renewable energy installations. (International Civil Aviation Organization, 2019).

So far, no significant safety accidents associated with solar panel systems are recorded. Nonetheless, a risk analysis for each project will also be followed by design and implementation. At first sight, airports tend to be a suitable location for solar photovoltaic ventures as airports typically lie on a low-lying site and have a wide area of 'un-useful' land surrounding runways, taxiways, and the airport buildings. The property near and at the airport is also not ideal for other users due to noise from low-flight traffic, environmental restrictions such as airspace penetration limitations, and wildlife protection. The airport itself constitutes a single large customer located close to such projects. The production of renewable energy from airports has increasingly grown, and numerous systems are already being used. It varies from the deployment on areas between the taxiway and runway structures to the construction on terminal or deck-roofs. Several airfields in the USA have constructed major schemes as well as airports in Germany, Africa, and the Caribbean, for example. Cochin International Airport (CIAL) is the first fully solar airport in India since 2016 (International Civil Aviation Organization, 2019).

The use of solar photovoltaic equipment at airports faces possible threats. The most critical risks found are: the impact of reflected glare on solar panels · thermal disruption from heat exposure and the effect on wildlife (especially potential rise in population of birds) • accessibility to (remote) areas by emergency services and • possible interference with Communication and Navigation Systems Depending on whether or not such threats have been mitigated. The Runway Safety Team at the airport should be engaged in risk management where main airport facilities make use of green energy; arrangements will be in place to ensure their stability, efficiency, and consistency in the case of disturbances to the supply of solar energy. Because of those mentioned earlier, the solar project should confirm with the Airport Master plan and the Airport Development Plan and will perform an Environmental Impact Assessment (EIA). Advice on glare risk (visual impact) provided by the Federal Aviation Administration (FAA), in collaboration with the Department of Energy (DOE) and endorsed by interim policy and technical advice, as a Solar Glare Detection Hazard Tool

(SGAHT).. (The International Federation of Air Line Pilots' Associations, 2018).

Glare from Panels:

Solar panels are engineered not to reflect but absorb most of the cloud irradiation. The panels are also covered by an anti-reflection film, even though the glass surface of the photovoltaic modules is also textured. Sunlight reflexes are usually not seen as a concern, nor do they affect air traffic, and numerous tests and studies suggest that solar panels do not reflect as much as standard windows, water surfaces, and snow (Fadnes, 2016). Buy as a standard mitigation procedure Impact assessment is necessary to be undertaken for glare analysis.

Design

The pilots were asked to undergo a glare experiment from the installed solar panels. It is intended to combine four exposure angles (0, 25, 50, and 90 deg) with two levels of exposure (1 and 5 s), generating the possibility of eight experimental conditions. The durations will be chosen because they represent a range of transit times at different speeds across solar installations. It should also be pilots who undertake a single test to ensure that no light is visible, thus creating a minimum of nine conditions. Each pilot will fly one of the Nine conditions for each flight. The order of tests was randomized for each pilot so that they did not know whether or not a distinct occurrence would occur in a given study. The questionnaire asked questions about the pilot's sun glare perceptions when flying, and some general demographic issues (JA, CK, A, A, & M, 2015).

Pilot Demographics

The pilots should be asked to verify their present age, sexuality, how long they fly if they are wearing lenses (and if so, what) and if they have had a corrective vision (and if so, how long ago). The pilot's interactions of direct sunlight, solar panels, and reflection from other objects were requested to be tested. For every individual, they are asked to show what phase of their flight they have experienced the glare (departure, take off, cruise, approach, touch-down). The ability to fly the airplane and the ability to read its devices disability (each of them on the 5-point scale: no deficiency, slight deficiency, mild impairment, extreme deficiency). Of regard to the blindness of other items, the origin of the illumination is to be suggested (JA, CK, A, A, & M, 2015).

Electromagnetic radiation (EMR): As per the inputs received by Avinor from Swedia which is equivalent firm as like Avinor in Sweden, to the effect that electromagnetic radiation from solar panels could pose a real threat to aviation safety and has completed projects until an existing regulatory structure is accessible now in Sweden. 27 In considering the issue, the U.S. Civil Aviation Authority, Federal Aviation Administration (FAA), found that solar cells do not affect as long as the system is at least 75 meters (approximately 50 feet) away from devices affected by electromagnetic radiation (Fadnes, 2016).

Birdlife: A research study of five distinct airports in the US has shown that solar farms have little influence on the life of birds near a runway. The research revealed that the number of larger birds has, in some instances have been marginally lower so that the probability of "bird-fly-crash" has decreased in comparison to the natural grass/vegetation alternative of the runway. The inference was that it is based on location and habitat. Some examples of solar farms located in the vicinity at airports are Changi Airport in Singapore, Gatwick Airport in London, Dusseldorf Airport in Germany (Fadnes, 2016).

Fire Risk:

By default, all electrical equipment bear a certain level of risk of fire. Even if Solar panels panel fires are uncommon, any fire concerning a photovoltaic site that too an airport will pose an increased risk to both passengers and firefighters. Pv modules with strings or central inverters have Direct Current (DC) at voltage levels. Usually, the DC electrical between electricals between the PV array and the DC insulation switch can not be separated. Pv systems are active power-limiting devices that prevent fuses from operating under short-circuit conditions that might result in a system failure being completely unnoticed. This scenario could present fire and electrical discharge risks, but decent system design, product range, and installation procedures can minimize those risk factors. In particular, reports were produced about facilities of AC insulator switches being misused in DC circuits resulting in an accumulation of heat inside the switch enclosure and thereby causing the fire. The usage of defective inverters or DC switches or the lack of insulator switches has triggered other reported accidents. Any shifting or link failure on the DC side will lead to a high-temperature flare or high-resistance failure that also can cause a fire. DC arcs can be hard to extinguish and endanger firefighters trying to combat the fire. Excellent design and regular testing, inspection, and repair are essential for managing risk. (Shipp, Holland, Crowder, Pester , & Holden, 2016).

Hail and Hurricane:

Solar panels, like every other outdoor device, are subject to changes in weather conditions. You can have heavy storms, high winds, or even hail on your panels, depending on where the solar panels are located. In general, solar panels are robust and can very well sustain unfavorable conditions and bad weather. National Renewable Energy Laboratory (NREL) had researched on 50,000 solar energy systems installed between 2009 and 2013, reveals that just 0.1 percent of all photovoltaic (PV) systems are confirmed to have been directly impacted by damaged or under-performing modules last year. Companies of solar panels check their goods to ensure that it can endure hailstorms. Solar panels are often checked and approved for hail resistance up to 25 mm (one cm) that fall by 23 m / sec (approx. 50 mph). Solar panels can be displaced from their position or destroyed by higher levels of water at strong winds and torrential downpours. That being said, solar panels are usually screened for storms by manufacturing companies. Most solar panels are rated to survive winds of up to 140 mph equal to up to 2.400 m. In comparison, even under heavy rain, the traditional aluminum and glass housings that support solar cells and make up a solar panel are extremely water-resistant (MARSH, 2017).

Is wood burning Carbon Neutral

Avinor has a wood-burning plant from where the energy for heating needs of the Airport is taken care of, claims that it saves around 2000 tons of equivalent of CO2 each year. Even though wood as a bio-energy may reduce long-lasting CO2 levels relative to coal and oil, the first impact of this bio-energy is a rise in CO2, aggravating the global warming over the crucial period to 2100, even if the wood compensates for coal which is the most carbon-emitting fossil fuel. Claiming that biofuels as carbon neutral like the European Union and others, misleadingly implies that forest growth is vigorous and completely offsets the biofuel production and combustion. The assumption of neutrality is not legitimate as it neglects the short term but decades to centuries-long, an upsurge of CO2 from biofuels. Presuming that biofuels are carbon-neutral, the detrimental effects of climate change will exacerbate before gains. Alternatively, specific dynamic models should be used to evaluate biofuel 's climate impacts (Sterman, Siegel, & R, 2018) The below image clearly shows tiny particles coming out of the chimney and a text outside saying “here we save environment for 2000 tons of CO2 per year”.

Considering the 2000 tons of equivalent savings and converting it to KWh equivalent. For every 0.38 kg of wood burnt, one KWh of energy can be produced. So for 2000 tons of wood being burnt, the electricity that is obtained is 5.263GWh, which is twice the amount of the energy that is required for district heating currently at Sola Airport.

Figure 30 light black smoke observed from the chimney of the wood-burning plant that indicates particles

Electric aviation

Electric vehicles are becoming increasingly widely popular, prices are declining, and buyers look for the first mass consumer hybrid electric vehicle, the Toyota Prius, launched in the 1990s. In addition to such charging batteries and their output, which should increase dramatically on a year-round basis, hybrid and even all-electric aircraft with seats of up to 100 passengers have no significant technological barriers. The first electric two-seater aircraft have already been built and controlled. Such aircraft are intended to be used for pilot training because these aircraft's operating costs, noise reduction, and zero local emissions are considerably lower. Minor airfields take electric aircraft as they allow business investments in aviation, but the local population is less affected. Commercial service is likely to be achieved in ten years in different countries by regional electrical hybrid aircraft with a capacity of 20 to 70 seats. For larger regional aircraft, the transition span of 15–20 years and intercontinental long-distance flights is expected to see new hybrid technologies where fuel and electric motors consumption is reduced and overall capacity increases.

- ***Emissions control.*** When all domestic aviation travel in Norway turns to energy, emissions of 1 200000 tons of CO2 equivalents can be reduced to a minimum. Converting energy removes oils, Nitrogen Oxides, hydrocarbons, and particulates. It means reducing energy conservation. Ninety-eight percent of energy in Norway is generated by hydropower, so that energy from the grid is almost wholly supplied from a renewable source.
- ***Low consumption of energy.*** An electric motor is much more potent than a combustion engine. Overall, the electric motor is more than three times as potent as fossil fuels in energy transformation. The combustion of hydrocarbons produces much more energy, but much energy has been lost as heat in comparison to the electric motor.
- ***Elimination of noise.*** In comparison to the combustion of fuel-burning engines, electric motors make much less noise. In addition to the recent development of powerful low-pressure fans attached to aircraft, electric motors can reduce noise, in comparison with conventional comparable-scale turboprop aircraft.
- ***Operation of small fields.*** The electric motors are compact and lightweight to provide additional acceleration power boost to allow rapid start-up and reverse thrust to slow down quickly after landing.
- ***Reduced running and repair costs.*** In comparison to conventional aircraft, scheduled engine maintenance for electronic aircraft is projected to be substantially smaller, and unplanned repairs are even lower. The cost of electricity is smaller than the present price of fuel. The increased amortization costs of the battery are heavily dependent on potential battery life.
- ***Upward departure and delivery.*** Electrical engines can be scalable, and new aircraft designs can allow vertical starting and landing capacities using several engines. Various innovative air transport schemes for air taxis for one to four-seater aircraft (less than 100 km) have been introduced (Reimers,

2018).

Energy Calculations

A calculation of the expected discharge in energy and power requirements for the operation of electric aircraft will be presented in this subchapter. Annual energy requirements are shown, and examples of needs relating to particular journeys and estimation of electricity requirements are presented. The fuel consumption of the airport (type JetA1) is based on the usage of fuel (type JetA1) at Stavanger airport, and an estimation of the energy needs of a typical aircraft and its energy needs for aviation at Sola is shown in Table 16. (Avinor AS, 2018).

Table 16 Estimation of a typical aircraft and its energy needs for aviation at Sola

Description		Comment
Fuel consumption [l/year]	**7000000**	
Energy content fuel [KWh/l]	**9,6**	
Annual energy demand aviation [GWh/year]	**672**	
Average power requirements [MWh/h]	**77**	Energy demand divided by 8760 hours, only an estimate to indicate what magnitude a future need can be.
Daily needs energy aviation [KWh/day]	**1800000**	Calculation
Number of air stays at Sola [number/year]	**About 35,000**	Based on statistics from Avinor's website, figures from 2018: Per flight stay, there is a landing and a departure (a total of two flight movements). During the first six months, there were 36 000 flight movements at Stavanger Airport.
Average energy demand per plane at Sola [KWh/flight]	**19 200**	Annual energy needs are divided by the number of stays at Stavanger Airport.

The energy consumption for the operation of the aircraft at Stavanger Airport is 672 GWh / year, more than 40 times the energy requirements for the airport construction and facility facilities (approximately 16 GWh / year). Today's aircraft need to operate is higher than the monthly airport maintenance requirement. Electrical aircraft are smaller and more effective than the aircraft today. The demand for electricity is rising, but the overall stock is decreasing. For example, Green Future AS estimates that an electric aircraft with fifty passengers traveling 190 km would need around 950 KWh of electricity.

Compare this to 2650 KWh of fuel for a Dash 8-100 with 38 passengers. The 36% (electricity demand divided by fuel requirements) is further used for estimating potential developments in electricity consumption at Stavanger Airport in Table 16. The estimation is not dependent, among other things, on the estimate: the 36%

ratio of demand for energy and fuel is dependent on an aircraft with a specific passenger count. This simplification does not consider that the various types of aircraft differ in weight, distance, modified loading of passengers, etc. 36 percent, a realistic estimate of the efficiency of a direct-acting motor with fuel-powered motors. The estimate shall not consider any possible adjustments in the number of flights/passengers. The estimate is based on all possible electric aircraft (Avinor AS, 2018).

Table 17scaling electric aviation

Forecast on Electric Aviation	
Annual energy demand aviation with fuel [GWh/year]	**672**
Average fuel power requirements [MWh/h]	**77**
Reduction energy needs when converting to electrical aviation [%]	**64 %**
Annual energy demand aviation with power [GWh/year]	**255**
Average power requirements [MWh/h]	**29**
Average energy demand per flight [KWh/flying]	**7 300**

The reason why Norway is well suited to introducing electric aviation is that technology is ideal for Norway's short-track network. Stavanger-Bergen is the first most crucial journey for an electric plane to and flying from Stavanger Airport. The distance from the air is about 100 miles. It provides an energy requirement of about 800 KWh (50 passengers – 190 km) on the Stavanger-Bergen journey when scaling to previously mentioned samples (50 passengers – 160 Km). The aircraft is expected to have a battery capacity of around 1700 KWh. It can, therefore, be expected that the electrical power required for charging will be between 1600 KW and 2400 KW, with a journey time of 30 and 20 minutes, respectively, for charging the aircraft with an hour of 1600 KW. According to a study carried out by the Department of Transportation Economics in 2015, 547 000 passengers were traveling between Bergen and Stavanger. An estimate of this route's (Typical Calculation for the electric plane from Stavanger airport to Bergen airport) energy needs would lead to electric aircraft (Avinor AS, 2018).

Table 18 Calculation typical journey by electric plane from Stavanger Airport (Avinor AS, 2018)

Calculation electric energy needs typical distance by electric aircraft – Stavanger – Bergen	
Energy needs to transport 50 passengers between Stavanger – Bergen [KWh/travel]	**800**
Number of travelers [passengers per year]	**547 000**
The number of flights per year [travel per year] (provided all aircraft have 100% passenger load).	**10 940**
Total Energy Needs Stavanger – Bergen [KWh/year]	**8 752 000**
The average number of trips per day	**30**

Average energy demand per day [KWh/day]	**24 000**

Table 18 shows that the energy demand is about half of today 's total energy needs for Stavanger Airport operation and a need that one could trade today without significant interventions in today's modern infrastructure. As more aircraft are required to reach this need, a short drive like this can increase demand for power. The statistics for energy and electricity usage for electric aircraft in the above table indicate that substantial research needs to be done to prepare and promote the facilities at airports. An average power requirement of 29 MW is four times higher than the electric current currently installed at Stavanger Airport, and 100% electrification requires that it is always available. The statistics are determined based on 100% aviation electrification. A comparison is made of the average electricity consumption per flight. With energy demand for the route from Stavanger to Bergen at 800 KWh, 7300 KWh shows that many aircraft types require significantly higher energy than the first electric planes can trade from Stavanger Airport. The electrification will be achieved step by step as the smallest jets are first introduced on the shortest routes, which will allow Avinor to learn and schedule in line with technological growth. Stavanger – Bergen can be run using the current energy supply scheme and adjusted to a potential model focused on the development of renewable electricity. However, to fully electrify aviation by 2040, you have to have a holistic strategy that takes into account the increases in energy and power requirements that you know to come with technological growth. The first electric aircraft will provide valuable Practice for further research, and these experiences must be drawn into the overall future strategy. The advancement of battery technology is one of the leading technical challenges associated with aviation electrification. The batteries must be more comfortable for electric aircraft to remain in the air and affordable to become a commercial option for electric aviation. Improvements in battery technology can be used in both aircraft and to reduce airport power. The first electric aircraft will likely be developed as hybrid varieties, with fuel like tip load and electricity back-up. Avinor is also producing and distributing biofuels. One can imagine that a hybrid solution of bigoted biofuels and electricity can be used to help future development. Such a solution would help to incorporate sustainable aviation earlier (Avinor AS, 2018).

Infrastructure at Airport

In addition to managing energy usage and obtaining and storing electric aircraft energy, the power must be transmitted to the aircraft. The figure below illustrates simple sketches about how power can be supplied to electric aircraft.

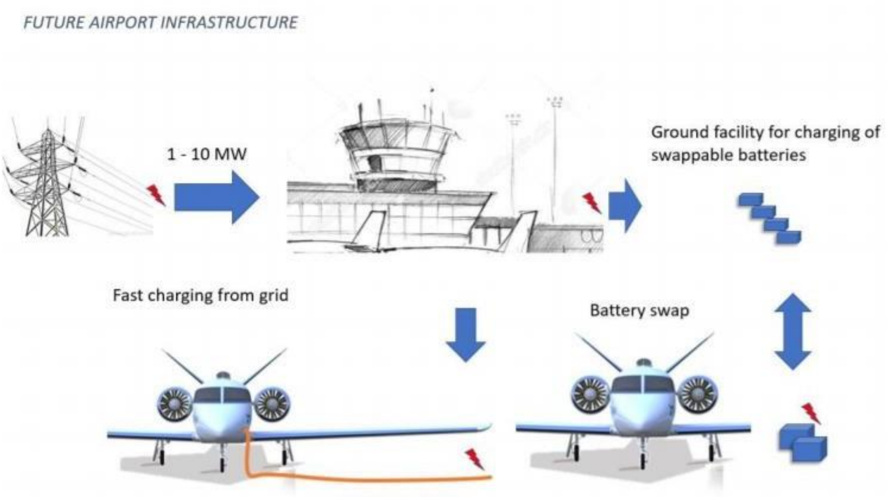

Figure 31 Sketch airport infrastructure – taken from Green Future Energy AS.

A new bridge at Stavanger Airport, called bridge 20, is to be built. This bridge should be ready for an electric aircraft. Based on the distance Stavanger-Bergen, at least 2400 KW electricity must be accessible at this bridge. Alternative energy supply solutions for electric bridge aircraft can be:

The power supply from the power supply is added to every setup space. It requires full cables. Batteries can be placed in any add-on area that can be paid if the phasing-up site is not used. Depending on the development of technology, another option may be to establish mobile interchangeable batteries. The batteries can then be loaded places incorrectly and transported to and from aircraft/bridges. Electric aviation poses challenges in the supply of electricity at an airport. A master plan must be developed early to ensure that future airports are planned in line with electrical aviation technological efficiency. In addition to Avinor, the following stakeholders should also participate in the Planning of Stavanger Airport: local actors, in particular Lyse/ Lyse elnett, but also the Enova consortium (Avinor AS, 2018).

Research environments.

When developing the concept of electric aviation, the Planning of management systems to facilitate the incorporation in the system of electric aircraft and their energy systems must already be facilitated. It must be ensured that the transformer capacity needed to meet the increased power requirements is available.

The capacity of Lyse elnett is expected to increase. The growth rate must be measured continuously according to technical advancement (Avinor AS, 2018).

"We must do this together, and it cannot solve aviation issues alone, we must do the work together. Maria Fiskerud, who manages the Nordic Network for Electric Aviation (NEA) and the Carbon Free Aviation 2045 Cluster, said. He also stated that all Nordic airports, along with the airlines and electrical aircraft manufacturers, should be collected to decide what needs to be implemented to make the electric aviation infrastructure available. The greatest challenge is to adapt and plan something that does not yet exist, and we don't know what it looks like. It is related to realistic activities but also funding for new initiatives. It's likely to come in and seek and have a minimum of time and incrementality as it takes construction time and means that the airports have time to adjust to the structure. It, of course, depends on the level of ambition – decisions, plans, and functional surfaces may be made, but a significant reinforcement seems risky in advance. There appear to be clear answers to what an airport can do. But in some situations, it might be best to wait a while if you do more realistic analysis, beginning with an essential study based on assumptions. However, we do not know how competitive the market is when we determine which airports can or can not run electric or hybrid VTOL. There is still an apparent danger on the market when significant electrification efforts are being made. Production can, nevertheless, be scheduled and prepared (Fiskerud, 2020).

The scenario for Electric Aviation Timeline

In the Norwegian Short Airfield Network, more than 20 destinations/routes range from 38 – 170 km and can quickly be flown with a battery-powered electric aircraft. This network would potentially involve the first electric fighter aircrew to act as a hybrid electric (i.e., an electric fuel engine generator as a back-up source), which can only be run by electrical power. For a few destinations, this is possible for the aircraft to move on to another airport or come back without charging, and only because the total distances flew are rather short utilizing electricity. For the simplicity of the hybrid power aviation solution, electrical aviation can be applied bit by bit, raising the chance of anomalies during the initial process. Battery tech is to have adequate power to provide for fully electric flights in a period of 10 – 15 years to handle over 1 hour or over 500 kilometers of flights. This electric transportation alternative would have a substantial and immediate effect if it was introduced, provided that most short airfield Norway flights cover ranges of less than 200 kilometers. (Public Service Obligation (PSO) network service flights provide State subsidies for the management of routes as traffic volumes for business ventures are inadequate.) (Reimers, 2018).

In addition to major suppliers such as Siemens, Rolls Royce, Safran, and a range of new enterprises, leading in a variety of sectors, technological innovation for electric airplanes is continually progressing and is broadly supporting the aviation industry. Several aircraft are in the testing phase, which will be a game-changer in the future. Most of the success in setting the basis for aircraft electrification specifically concerns the accelerated development of automobile batteries and electronics over the past few decades (Reimers, 2018). Within five years, it can reasonably be in business service. In the final analysis, this kind of development solution may make sense for larger aircraft, too, provided it can be paired with a lift-based and energy-efficient cruise mode. Different timeline scenarios were suggested by various research articles and electrification organizations. Moving rapidly is critical to commercialize and gain profits as soon as possible for start-up companies. Instead, for the developed aviation companies, it is more a combination of not going too quick and carefully exploring new ideas, and not going too slowly and getting left behind and overtaken by newcomers. In the previous year, it has been apparent that the global aviation sector is serious about its electrification activities and meeting the severe political desire to move to less carbon-intensive air transport. Growing numbers of initiatives and events have started and are supported by substantial financing.

Further announcements such as the agreement between Airbus, Siemens, and Rolls Royce to build electric engines for aviation can be anticipated shortly. Accreditation continues to be a critical factor forward. But when those businesses and entities with top aircraft technical experience and clearance authorities all share the same goal of safe and emission-free travel, this high-priority electrification work will make significant progress in the near future (Reimers, 2018).

Figure 32 Scenario for development of electric aircraft concerning battery density and comparable range (Reimers, 2018)

While the information presented in this document provides an overview of the reasons to consider renewable energy and the different types of renewable energies currently available, each airport's circumstances are unique, and States and individual airport operators will need to analyze their specific situation to determine which projects are feasible and desirable. To illustrate the range of different projects available, a series of case studies follow demonstrating several renewable energy initiatives from around the world. While these examples are specific to the locally available sources of energy produced and the regulatory environment in those specific locations, they provide an overview of considerations, costs and benefits, and lessons learned (International Civil Aviation Organization, 2019).

Discussion and Findings

Airports generally consume a large amount of energy(a lot of energy) for their operations. The features of airport energy usage, driven by several factors, are stochastic, nonlinear, and complex. In scientific research, electricity use is based mostly on terminal buildings, but these are just part of the entire airport. Hence a promising future area of study is enormous scope in all aspects of energy efficiency at airports. In airports, critical energy users can be split between the airport's side and landside. Consumers of airborne resources are mainly airfield lighting and radio navigation systems. Landside energy consumers are necessarily an airport terminal building because it acts as a node for the processing of passengers and cargo and because of the significant number of facilities required for operation. HVAC, lighting, and ICT systems are often the most critical energy consumers on airports, and new methods of reducing energy usage in these facilities should be explored. Electricity is the dominant source of energy because the supply of primary airport energy users and the protection of air traffic operations are important. This electricity is generally provided by a power company from the commercial grid. Over the past few years, however, other energy sources such as CHP plants or clean energy technologies can be found in the research literature and airports.

However, given their unique characteristics and their effect on air traffic health, a compatible airport and such energy sources must be developed soon. Currently, rising energy usage is a priority for airport management. The following categories can include improved control systems and equipment installations, improved HVAC systems and lights, and modern activity management systems that help to improve and maximize the energy efficiency of the airport. Modeling and simulating energy usage at airports can also play an essential role in reducing consumption. The creation of more specific airport environment methods is, therefore, essential but should concentrate on airports globally and not just on the building of the terminal. Finally, the use of EPIs informs energy management about energy performance. Still, it does not provide information as to the reasons for excellent or poor energy consumption. Because of the different conditions and factors involved, it can not be used directly to benchmark other airports. New precise benchmarking methods for airports need to be developed that take their characteristics into account and make them comparable (Ortega Alba & Manana , 2016).

This section discusses on Significant observations on electricity consumption that are identified at Stavanger Airport. Annual consumption of just under 16 000 000 KWh / year is reasonably stable. In winter the pressure is significantly higher than in summer. Monthly intake is 1 150 000 KWh or more. The lowest intake takes place primarily in the summer. Winter consumption between 1 600 000 and 1 700 000 KWh / month is the largest. Instantaneous power demand (KWh / h) is generally in the summer, between 1350 KW and 2000 KW, and in the winter, between 2000 and 2500 KW. The average consumption recorded in January 2014 and January 2016 is approximately 3000 KW. Consumption seldom reaches 2500 KW. The average power life is 5200 to 6000 hours. The longer the running time, the lower the ratio of overall power needs and average power demands. 8760 hours of usage lead to continuous year-round power requirements.

Consequently, the usage time of 6,000 hours is relatively high and limits power flow possibilities. The study provides examples of situations in which this is possible. The highest electricity requirements occur in times when the outside temperature is around 0 ° C. It can be connected with snowmelt and additional electric boiler installations. There is a disparity between the power needs day and night with lower night demand and higher morning and day demand. It provides possibilities for today's power movement. Stavanger Airport is expected to be connected by automatic doors with days of high winds and high energy needs for heating. There are no wind measurements that suit consumption estimates, so the assumption was not checked in the model. At Stavanger Airport, energy conservation was implemented by the report. Measures to rising energy demand were suggested in this project (Avinor AS, 2018).

Summary of Test measurements at Stavanger airport

The summary of the test measurements and comparison of results from simulation using PV GIS at Stavanger Airport is given below.

Table 19 Comparison of results from simulation (PV GIS)

Description	Scenario 1	Scenario 2	Scenario 3
Angle	**45**	**20**	**10**
Azimuth	**0**	**0**	**90/ -90**
Number of installed solar panels [pcs.]	**24 500**	**40 800**	**60 000**
Installed solar area [m²]	**40 400**	**67 300**	**99 000**
Simulated panel model	**REC280 TP**	**REC280 TP**	**REC280 TP**
Installed solar power [KWp]	**6850**	**11400**	**16800**
Simulated annual energy production [MWh/year]	**6492**	**10375**	**13824**
Specific performance [KWh/year/KWp]	**948**	**868**	**822**
Performance per solar area [KWh/year/m²]	**162**	**154**	**140**
Loss due to shade	**7%**	**6%**	**1%**
Reduction due to experience from test measurements	**5%**	**5%**	**5%**

In 2016, the solar specialist mounted ten mono and ten polycrystalline solar panels on the Stavanger airport as a test laboratory for the development of more prominent technologies as well as for the effect of various tilt and azimuth angles on development. The findings after one year of testing demonstrated significantly higher average performance of polycrystalline panels (KWh / KWp / year) than mono-crystalline panels, even though mono-crystalline panels are more labeling. In the Solar Norway Specialist 's view, polycrystalline solar panels can function better than anticipated, and polycrystalline panels can perform better than mono-crystalline with diffuse radiation (Fadnes, 2016). The alignment of the solar modules towards the sun also affects the quantity of electricity generated, and experimental findings have shown that the South facing panels have the highest average panel output as predicted. As per the study, the installation in East / West led to almost 20 percent lower production per panel than the installation in south-facing 15 °. This is a significant disparity than both test results t the site and the simulations provided by the solar specialist.

Both Norconsult and the Solar Specialist simulated values are higher than actual output. The solar specialist reports that the radiation recorded for the period from Dec 2016 to Nov 2017) was 10 percent lower than the simulated results in use. The planned installation at Stavanger Airport is comparatively small and not configured much like in a more massive installation. However, from simulations results, a decrease of approximately 5 percent is applied (Fadnes, 2016) .

To demonstrate how production differs due to the various configurations, three scenarios were analyzed with the same number of installed solar panels of about 24,500, which turns out to be the most significant number with 45° inclination considered to accommodate the allocated area. Results show that there is high production with the 45° inclination and azimuth of 0° (facing south).

Table 20 Summary production 24 500 panels of 280 Wp with three different configurations.

Configuration	Annual production from 24500 panels [KWh/year]
45° south	**6304525**
20° to the South	**5981675**
10° east/west configuration	**5360355**

Optimum Energy Scenario using PV GIS

Based on various trial and error method, the optimum output from the solar panels is obtained from mounting the panel at an angle of 42 degrees with an Azimuth of 4 degrees to the axis (calibrating scenario 1). Yearly PV production will be approximately 6504 MWh. Total loss considered will be 11.6% (both shade and difference from actual readings as specified above in the report).

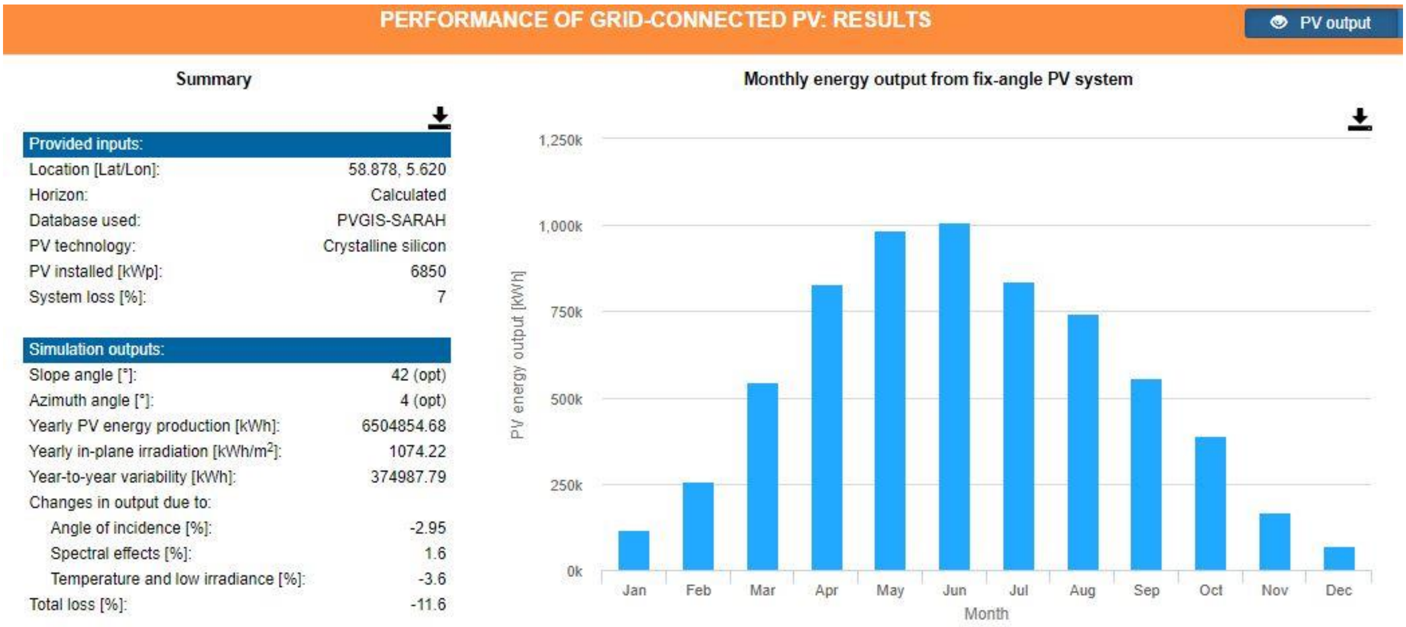

Figure 33 Optimum Energy Scenario (PV GIS)

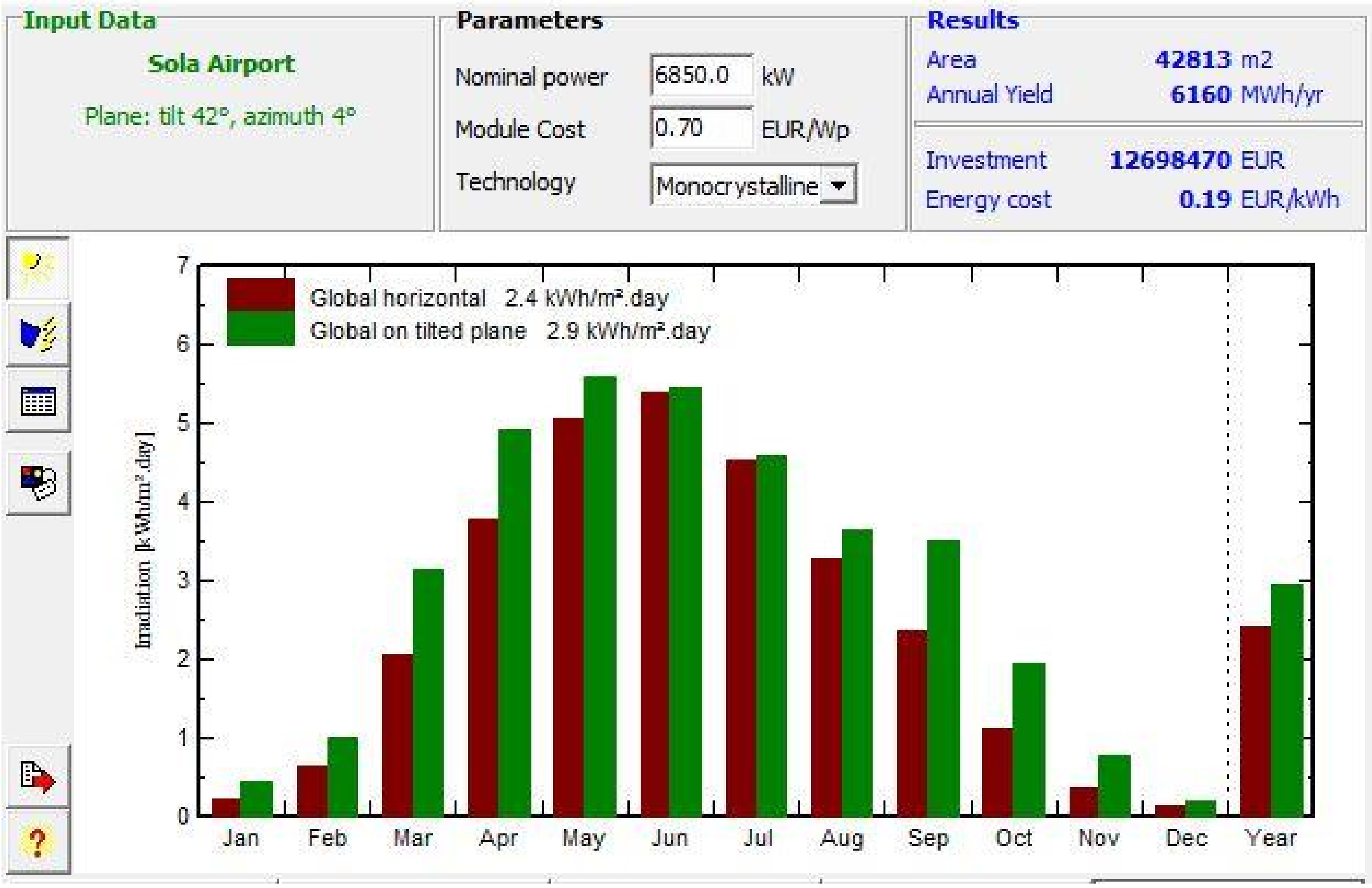

Figure 34 Scenario 1 Calibrated Results from PV Syst

Thereby the final simulated energy that we could obtain a solar potential of 6.160 GWh/year from installed solar panel area of 42813 square meters. Likewise, by various simulation trials, we could obtain the solar potential for the initial solar installations of 2 hectares to be 2.877 GWh/year and 30.831GWh/year for the planned 22 hectares.

Table 21 Results for simulated potential Vs. Installed Solar Area

Year	Description	Power requirements [KW]	Energy needs [GWh/year]	Simulated Solar Potential Energy [GWh/year]	Installed Solar Area in Hectares
2019	Today scenario	3 000	16	2.877	2
2025	Before electrification of aviation.	2 300	14	15.191	11
2030	After the introduction to electric aircraft.	12 500	25	31.62	22

The above table shows the summary of simulated results from both PV GIS and PV syst and forecasting the solar potential to the installed solar area along with the energy needs. There is a decline in energy need forecasted for 2025 because of the energy-saving measures, and the efficiency of the panels would increase, whereas the energy requirements remain unchanged. But to make it more clear, different scenarios have been considered for the result based on the Positive Energy District model to perform a 'reality check' (2020, s. p5) on the results. The results shall be analyzed based on the functions of PED, which will enable us to understand the different possibilities that could happen in the future. The functions of PED is discussed based on the various assumed scenario. The scenario is well defined and assumed clearly to understand energy distribution and energy consumption. Each scenario consists of various criteria such as year, increased energy production due to increased energy efficiency of panels, the future technology and energy management measures that could pave the way for energy reduction and various alternatives to produce energy.

Discussion based on Functions of a PED

Energy Efficiency Function

Let's assume that with the technology that we would likely have now and considering the trend at which the solar panels have been evolved, there will be an increase in energy efficiency in solar panels. The world record rates of performance are 25.6 percent for monocrystalline Silicon Systems and 21.3 percent for both cells and panels, respectively, and 23.8 percent for Multi-crystalline Silicon. Interestingly, although this story is under one year old, it is out of date: the record for monocrystalline photovoltaic cells is now 26.6%! (Dunbar , 2017). So we consider there will be 25% more of increased energy efficiency per square meter in the solar panels by 2040, and the value considered is minimal.

Energy Flexibility Function

As of now, the energy management measures at Sola airport contributes to about 18.1% of the energy out of the total energy consumed at the airport. In 2040 there may be an improved method of insulation, and the energy-saving measure could help us to minimize the energy consumption, furthermore by 25% (minimal value).

Energy Production Function

For a PED, it is mandatory that the source of the energy that is harvested to be renewable. Here, the energy at the airport is obtained at the airport using solar panels. Energy consumption forecasted in 2040 shall be in three assumptions

- Consumption as Usual
- Consumption with planned Electric Aviation
- Consumption with full Electric Aviation

According to the literature review, the yearly consumption of the assumptions mentioned above is 16GWh, 25GWh, and 672GWh, respectively. So, in total, 50% of today's demand shall be curtailed with the help of energy-saving and energy efficiency in 2040, which gives us a yearly saving of 8GWh of energy if the energy demand increases by 25% in BAU and the planned electric aviation demand in 2040 to be 40GWh per year. Therefore, a savings of 50% in today's energy demand will reduce the demand to 32 GWh per year in 2040.

The total BAU demand in the year 2040 for the Stavanger airport will be 12GWh, without any electric aviation. Considering the excess energy need for planned electric aviation and full electric aviation at Sola Airport, the energy review of the sola airport's achievement towards PED for the assumptions is shown in the table below.

Table 22 Sola Airport Achievement towards PED in 2040

Description	Assumed Energy Demand [GWh/year]	Simulated Solar Potential Energy for 2040 [GWh/year]	The ratio of Production to Consumption	% achievement towards PED
Energy Demand for BAU (no electric Aviation)	**12**	**31.62**	**2.635**	**263%**
Energy Demand for Planned Electric Aviation	**32**	**31.62**	**0.968**	**97%**
Energy Demand for Full Electric Aviation	**672**	**31.62**	**0.047**	**5%**

So, by the table above, only with solar energy, the possibility of Sola Airport becoming a Positive energy District is not possible. May be considering the Wind Farm and other renewable energy sources, Sola Airport may be a Positive energy District. On-demand for Full Electric Aviation at Sola Airport, it achieves only 5% of energy demand (for the 22 hectares of the solar area allotted). Some alternate energy harvesting possibilities shall be planned to achieve the required power demand for full-electric aviation.

Alternate Energy Harvesting Possibilities

Some of the other alternative energy harvesting technologies that shall be implemented to achieve full electric aviation energy need of 672GWh of energy shall be as follows. Some are inspired by other airports all around the world.

Solar Trees

Solar trees function the same as real ones since they consist of leaf-like solar panels connected to metal branches that use sunlight to generate power. Solar trees can be used as an alternative to solar rooftop systems. They take nearly a hundred times less area to generate the same amount of energy as a horizontal solar power plant and, as such, are an alternative for land and space scare economies (IRENA, 2019).

Figure 35 Solar Trees (Twitter Photo)

Solar Carports

Solar carports are solar panels mounted on the surface, such that parking and driving lines can be placed underneath it to form a carport or a driveway. They are a perfect alternative or an add-on to the conventional systems installed, with the advantage of the roof angle, form, and orientation of the system were independent. In addition to offering shade for the vehicles below, they can produce electricity efficiently and thus offer several benefits. First, the electricity generated can be used for EV charging along with a well-built charging network, thus reducing the costs of operating the vehicle (Thurston, 2019). Secondly, they can improve power storage by integrating battery storage and trying to make the solution independent of sunshine hours. Third, they are easy to customize and save space, unlike ground-level systems, because they do not need much framework or ground on which to place them (IRENA, 2019).

Figure 36 Carports (Image: Flickr, Jean-Louis Zimmermann)

Agrophotovoltaic

Agrophotovoltaic (APV) integrates solar photovoltaics with farming on the very same field and is made up of vegetation undergrounded photovoltaic arrays. Even though the framework was designed a long time ago, very less consideration has been paid to it since recently when several scientists approved the benefits of agricultural production under the shade provided by solar modules. These include increased power generation, increased crop yields, and less water being used for plants (B. M., et al., 2019).

For both crop production and photovoltaic arrays, APV is a win-win situation. Numerous food crops, for example, tomatoes, are better cultivated in the shade of solar panels, since they are prevented from the direct sunlight and have lower losses of water mostly through transpiration. A significant advantage of solar panels is that they become more efficient. The cultivation of crops underneath the installed solar panels reduces the panel temperature as the plants below are cooled by their natural transpiration (Hanley , 2019).

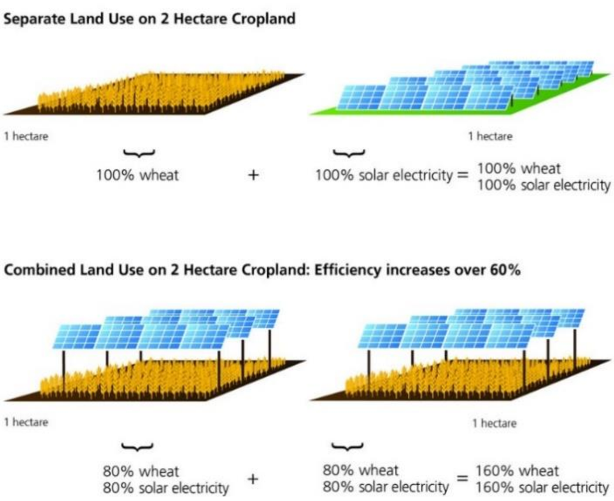

Figure 37 Agrophotovoltaic system (Photo Fraunhofer ISE The dual use of agricultural land increases the land-use efficiency by 60 percent)

Conclusion

Several scenarios and simulations have been made with the help of PV syst and PV GIS to understand the energy demand, distribution, savings, and energy consumption at the Stavanger Airport. At present, Stavanger airport demands energy less than 16 GWh per year, but in the future, say 2025, the energy demand may decline to 14 GWh per year. Due to the electrification of planes, the energy needs may increase up to 25 GWh in 2030. Energy demand in 2040 is forecasted to be 32 GWh considering the maximization of electrification at that point in time.

There has been a clear intimation given on energy demand that is considered for this research that only direct electricity needs of the airport will be taken into account as the energy for the heating the buildings is taken care of a nearby wood-burning plant. Moreover, the claim that wood-burning saves 2000 tons of CO2 is not carbon-neutral. There is smoke observed from the chimneys from the wood-burning plant that indicates the particles emitting CO2. Serious attention should be given to such practices as this might lead to a false on the deciding authority in the future. Energy savings and its management also play a vital role in deciding the Stavanger airport as a PED as it accounts for a minimum savings of 25% in total energy demand. Energy efficiency also accounts for the same amount of savings, and therefore, a savings of 50% can be expected in 2040.

Selling the surplus electricity to the grid in summer and getting it back by winter in a cold country like Norway seems to be a viable choice rather than storing the excess energy produced due to the enormous battery need. Hydrogen batteries don't stand a chance because of their low efficiency and high price. A Solar Plus battery suitable for a minimum back up for a day or two is highly recommended.

Generally, solar panels are waterproof and are made of tough materials, but there should be safety considerations regards to glare, fire, storm, and EMC.

By considering all the factors, "It is clear that by 2040, the Stavanger Airport cannot be transformed into a Positive Energy District with Solar Power, and including the possibility of fueling Electric Aviation. Simulations show that the 22 hectares of the allotted solar area can only produce only the maximum power of 31.62 GWh per year for the required energy of 32gW per year(which is around 97%) considering planned electric aviation (to power up the five electric planes planned by the airport authority by 2025). Still, there is a possibility that the Stavanger airport could be transformed into a PED by a congregation of several renewable energy sources such as wind along with some methods to achieve maximum efficiency from the renewables. (for example, Solar Tree and Solar Carports, coupled with the source of wind energy.) It is quite an impossible task to achieve the full electrification demand of 672 GWh per year only with Solar energy with current technology. Further research on this paper shall be a detailed policy and cost analysis relating to today's demand and future needs.

References

Hanley , S. (2019). *Fraunhofer Reports Combining Farming With Solar 186% More Efficient In Summer Of 2018.* Clean Technica.

MARSH, J. (2017). Solar Panels and incliment weather. *Energy Sage*.

ACI EUROPE. (2009). *4 Steps to Carbon Neutrality*. Retrieved from Airport Carbon Accredition: https://www.airportcarbonaccreditation.org/

AECOM Australia. (2020). *Clean energy and infrastructure: Pathway to airport sustainability* . Retrieved from CEFC: https://www.cefc.com.au/media/402338/cefc-pathway-to-airport-sustainability.pdf

Airport Council International. (2017, 06 05). *Energy Efficiency*. Retrieved from Aviation Media: http://www.airport-world.com/features/environment/6188-energy-efficiency.html

Avinor AS. (2018). *Stavanger lufthavn - Sola Konseptutredning hovedrapport.* Stavanger: Avinor.

Avinor AS. (2019). Årsrapport Avinor . Avinor.

Avinor AS. (2020). Retrieved from Energy Savings: https://avinor.no/en/corporate/airport/stavanger/community-and-environment/energisparing/

B. M., B. G., G. A., Obergfell, T., R. C., & Schindele, S. (2019). *Combining PV and Food Crops to Agrophotovoltaic ? Optimization of Orientation and Harvest.* doi:10.4229/27thEUPVSEC2012-5AV.2.25

Baxter, G., Srisaeng, P., & Wild , G. (2018). *An Assessment of Airport Sustainability,Part 2—Energy Management at Copenhagen Airport.* Basel, Switzerland: MDPI.

BB Computerteknikk AS. (2019). *Stavanger Airport Sola.* Retrieved from BBC: https://www.bbcairport.com/no/airport/stavanger-airport-sola/

BBC News Report. (2019). *Climate change: Should you fly, drive or take the train?* Retrieved from Science & Environment: https://www.bbc.com/news/science-environment-49349566

Bhattacharya, T., Chakraborty, A. K., & Pal, K. (2014). *Effects of Ambient Temperature and Wind Speed on Performance of Monocrystalline Solar Photovoltaic Module in Tripura, India.*

Canadian Urban Institute. (2012). *The Value of Energy Mapping symposium Report.* Her Majesty the Queen in Right of Canada.

Clear (Comfortable Low Energy ARchitecture). (2020). *Sun Path Diagrams*. Retrieved from https://www.new-learn.info/packages/clear/thermal/climate/sun/sunpath_diagrams.html

Climate Data. (2020). *US Climate Data.* Retrieved from https://www.climatedata.eu/climate.php?loc=noxx0035&lang=en

COWI AS , Avinor AS. (2020). *NOT-RIE-002: ELNETT21 AVINOR New Solar Location.* Stavanger: COWI AS.

Coxworth, B. (2011). *Using solar power to keep runways ice-free*. Retrieved from News Atlas: https://newatlas.com/solar-powered-runway-de-icing/20520/

Dunbar , R. (2017). *How Efficient Will Solar PV Be In The Future? 10-Year Predictions For The Industry.* clean techna.

Elisa Peñalvo-López 1 ID, F. J.-C. (2017). *A Methodology for Analysing Sustainability in Energy Scenarios.* Basel, Switzerland.: MDPI.

Energy.Gov. (2019). *Solar-Plus-Storage 101.* Retrieved from Energy Efficiency and Renewable Energy: https://www.energy.gov/eere/solar/articles/solar-plus-storage-101

ENOVA. (2019). How to get an electric future without the fuse going. Avinor.

Fadnes, F. S. (2016). *RIEn-N03 - Stavanger lufthavn, Sola - vurdering strømproduksjon fra solceller.* Stavanger: Norconsult AS.

Fadnes, F. S. (2019). *Storskala demokonkurranse - effektbehov og produksjons- og lagringsanlegg Stavanger lufthavn.* Stavanger: NorConsult.

Fiskerud, M. (2020). *Electric aviation has arrived and will be here to stay*. Retrieved from International Airport review: https://www.internationalairportreview.com/article/114071/electric-aviation-arrived-here-to-stay/

Gendler, I. (2018). *Solar Plus Storage Systems.* Retrieved from Isaac's science blog: https://isaacscienceblog.com/2018/02/26/solar-plus-storage-systems/

Hinterberger, R., Gollner, C., Noll, M., Meyer, S., & Schwarz, H.-G. (2020). *Reference Framework for Positive Energy Districts and Neighbourhoods.* Urban Europe.

Hjellbrekke, A. J. (2018). *Stavanger Airport - innovative energy solutions - battery technology.* Stavanger: Norconsult.

International Civil Aviation Organization. (2019). *A Focus on the production of renewable energy at the Airport site.* Quebec, Canada.

IRENA. (2019). *Future of Solar Photovoltaic: Deployment, investment, technology, grid integration and socio-economic aspects (A Global Energy Transformation: paper).* Dubai: International Renewable Energy Agency.

JA, R., CK, H., A, M., A, M., & M, B. (2015). *Evaluation of Glare as a Hazard for General Aviation Pilots on Final Approach.*

Ko, Y. D., Jang, Y. J., & Kim, D. Y. (2017). *Strategic airline operation considering the carbon constrained air transport industry.* J. Air Transp. Manag. 62. doi:https://doi.org/10.1016/j.jairtraman.2017.02.004

Muthyal , R. (2013). *HOW TO USE SUN PATH DIAGRAM TO ESTIMATE THE EFFECT OF SHADING ON THE PV ARRAY?* Retrieved from First Green Consulting Pvt Ltd: https://firstgreenconsulting.wordpress.com/2013/06/09/how-to-use-sun-path-diagram-to-estimate-the-effect-of-shading-on-the-pv-array/

Nordic Network for Electric Aviation (NEA). (2020). *Electric aviation has arrived and will be here to stay*. Retrieved from International Airport Review: https://www.internationalairportreview.com/article/114071/electric-aviation-arrived-here-to-stay/?__cf_chl_jschl_tk__=25ca2e2e75eda68f4e47593714a09af2bc609b7e-1589234820-0-ARL2kfPu0wCVSEbQPb02KJAZfOfgFML22KCmtvmD-7WCrqyyHf9ixHUh1rDs--PCsFg07h7QnEzbb92NPSO

Optimizing Energy Savings - Airport. (2012). Retrieved from saineng.com: http://saineng.com/wp-content/uploads/2012/08/Airport-Terminals-Efficiency.pdf

Ortega Alba, S., & Manana , M. (2016). *Energy Research in Airports: A Review.* Basel, Switzerland: MDPI.

PHOTOVOLTAIC GEOGRAPHICAL INFORMATION SYSTEM. (2019). *PVGIS Interactive system*. Retrieved from https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#PVP

Post Note. (2006). *Carbon footprint of electricity Generation.* London: Parlimentary office of Science and Technology. Retrieved from https://www.parliament.uk/documents/post/postpn268.pdf

Reimers, J. O. (2018). *INTRODUCTION OF ELECTRIC AVIATION IN NORWAY.* Stavanger: Green Future AS.

Romero, A. K. (2014). *Siting Solar Photovoltaics at Airports.* California: National Renewable Energy Laboratory.

Schluneger, M. (2015). *OPTIMIZE ELECTRICITY USAGE IN AIRPORTS.* Retrieved from https://energie-industrie.com/media/Presentation/airport_blog_510345.pdf

Shipp, M., Holland, C., Crowder, D., Pester , S., & Holden, J. (2016). *Fire safety and solar electric/photovoltaic systems.* BRE.

Sreenath Sukumaran a, K. S. (2017). *Fully solar powered airport: A case study of Cochin International airport.* cochin.

Sterman, J. D., Siegel, L., & R, J. N. (2018). *Does replacing coal with wood lower CO2 emissions? Dynamic lifecycle analysis of wood bioenergy.* Environmental Research Letters. Retrieved from https://iopscience.iop.org/article/10.1088/1748-9326/aaa512/pdf

Steve Thurston. (2012). *International Airport Review*. Retrieved from Solar powered Southampton: https://www.internationalairportreview.com/article/7823/solar-powered-southampton/

The International Federation of Air Line Pilots' Associations. (2018). *Solar Panel Installations at Airports*. Retrieved from https://www.ifalpa.org/media/3101/18pos08-solar-panel-installations-at-airports.pdf

Thurston, C. W. (2019). *The influences driving solar carports*. Retrieved from PV magazine: https://www.pv-magazine.com/2019/03/15/the-influences-driving-solar-carports/

Uysal , M. P., & Sogut, Z. M. (2017). *An integrated research for architecture-based energy management in sustainable airports.* Ankara, Turkey: Elsiever .

Weather Atlas. (2020). *Monthly weather forecast and climate, Stavanger Norway* . Retrieved from Yu Media Group d.o.o: https://www.weather-atlas.com/en/norway/stavanger-climate

WindFinder. (2020). *Yearly wind and weather averages for Stavanger lufthavn/Sola.* Retrieved from WindFinder: https://www.windfinder.com/forecast/stavanger_sola

World Meteorological Organization. (2008). *Guide to Meteorological Instruments and Methods of Observation.* Geneva: World Meteorological Organization (WMO).

Appendices

Abbreviations

PV - Photovoltaic

BAU - Business as Usual

PED - Positive Energy District

GIS - Geographical Information System

CPH - Combined Heat and Power

HVAC - Heating, Ventilation and Air Conditioning

ICT - Information and Communication Technologies

EIA - Environmental Impact Assessment

LCOE - Levelized Cost of Energy

EMS - Energy Management System

APU - Airport Power Unit

AMR - Airport Movement radar

EMR – Electromagnetic Radiation

APV - Agrophotovoltaic