Bachelor's thesis

Kasper Servold Oppi
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Use of renewable energy and hydrogen storage for a carbon-negative village

Bruk av fornybar energi og hydrogenlagring for en karbonnegativ landsby

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Preface

This bachelor thesis is the final assignment for the study program ”Renewable Energy” at the Norwegian University of Science and Technology. This thesis was made in cooperation with the High North Development Group, and the aim was to create a carbon-negative village in Kirkenes.

Prof. Steven Boles was the internal supervisor for this thesis and we are grateful for his guidance and assistance during the period.

Arnfinn Mentyjærvi has acted as a bridge between us and High North Development Group, and as an external supervisor. We want to thank him for his insightful tips, help, and support throughout this period.

Additionally, we want to thank the company, High North Development Group, for handing us the opportunity to work on an exciting future-oriented project and providing valuable data for our calculations. We are also grateful for the fun and inspiring excursion to Kirkenes at the end of March, which gave a great insight into the project. This enabled the completion of the bachelor thesis and made the process educational and enjoyable.

Trondheim, 20.05.23

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Abstract

This bachelor thesis was written as a part of a larger project, Nothing Hill, where the aim is to transform an old hospital from 1955 into a modern student campus. The objective of this project is to create a carbon-negative village, where the system offset more carbon emissions than what it contributes. This report has evaluated the amount of energy produced from solar panels and wind turbines, hydrogen as an energy storage method, and the energy budget for the Nothing Hill project.

The High North Development Group initiated the Nothing Hill project in response to challenges in the Kirkenes area. By revitalizing the old hospital and implementing sustainable energy solutions, the project aims to challenge negative perceptions associated with Kirkenes and foster innovation for companies and students.

In this thesis, the impact of factors on PV-panels such as tilt angles, temperature correction, shading and the albedo effect were all investigated. With temperature correction included, the production was estimated to increase by 24,7%. Tracked panels proved to be the optimal solution. When combined with wind turbines placed at an optimal location, the system can provide 1980 MWh of energy annually. During the summer, the energy production will exceed the consumption. This necessitates effective storage solutions to utilize the energy through the winter. Various options, including thermal energy storage, lithium-ion batteries, flow batteries and hydrogen were investigated. Hydrogen storage was evaluated to be the most suitable choice. By implementing a PEM (Proton Exchange Membrane) electrolyzer, compressed hydrogen storage, and a PEM fuel cell, an overall energy efficiency of 40.5% can be achieved. The proposed storage system will have a high cost, but the viability will increase with the expected coming reduction in technology costs and with possible financial support.

Sustainable solutions are crucial for the success of the project. While achieving a carbon-negative status may be highly challenging due to unaccounted building materials, striving for a balance between consumption and production could be a good alternative. The main building used 175 kWh/m^2/year in 2021. Simulations indicated that achieving an energy-plus house status for the main building would require a reduction of consumption to 90 kWh/m^2/year, while the TEK17 standard can be achieved at 125 kWh/m^2/year. Consumption will directly influence the surplus energy available for storage. To achieve self-sufficiency, the building must reduce the consumption by 68.8%. Given the grid overload in Kirkenes, the most favorable strategy entails a hybrid energy storage approach and selling surplus energy back to the grid. This will make it possible to buy the energy back during periods of low production.

In conclusion, this thesis evaluated that solar and wind power can generate sufficient energy for the main building in the Nothing Hill project. Hydrogen is regarded as the preferred option for energy storage. However, this solution will require a substantial storage unit and collaboration with the grid to ensure year-round self-sufficiency. While the building may not achieve a total carbon-negative status, it is expected to qualify as an energy-plus house if the energy consumption is significantly reduced and the heat demand is covered from geothermal energy.

Sammendrag

Denne bacheloroppgaven ble skrevet som en del av et større prosjekt, Nothing Hill, der et gammelt sykehus fra 1955 skal ombygges til en moderne studentcampus. Et av målene med dette prosjektet er å skape en karbonnegativ landsby, hvor landsbyen kompenserer for karbonutslippet ved bruk av fornybar energiproduksjon. Gruppens oppgave i prosjektet var å regne ut mengden energi produsert fra solcellepaneler og vindturbiner, vurdere hydrogen som energilagringsmetode, samt evaluere energibudsjettet for prosjektet.

Prosjektet Nothing Hill er et samarbeidsprosjekt mellom 20 bedrifter, ledet av High North Development Group. Det startet i 2021, og er et resultat av en rekke negative faktorer tilknyttet Kirkenes og det arktiske området de siste årene. Det nye bygget har som mål å være selvforsynt med egenprodusert grønn energi, og dermed oppnå status som plusshus.

I denne oppgaven ble effekten av faktorer som helningsvinkel, temperaturkorreksjon, skygge og albedoeffekten på solcellepaneler undersøkt. Produksjonen ble estimert til å øke med 24,7% ved temperaturkorrigering. Solcellepaneler som endrer vinkel etter solens posisjon viste seg å være den optimale løsningen, og i kombinasjon med optimalt plasserte vindturbiner kan systemet oppnå en årlig produksjon på 1980 MWh. Om sommeren vil energiproduksjonen overstige forbruket. Dette krever effektive lagringsløsninger, for å kunne utnytte energien gjennom vinteren. Ulike lagringsalternativer som termisk energilagring, litium-ionbatterier, flowbatterier og hydrogen ble undersøkt. Hydrogenlagring viste seg å være det best egnede valget for dette prosjektet. Ved å implementere en PEM-elektrolysator (Proton Exchange Membrane), lagring under høyt trykk og en PEM-brenselcelle kan man oppnå en samlet effektivitet på 40,5%. Det foreslåtte lagringssystemet vil ha høye kostnader, men levedyktigheten vil øke med den forventede reduksjonen i teknologikostnader og med eventuell økonomisk støtte.

De ulike definisjonene for bygninger avgjør hva slags status Nothing Hill kan oppnå. Det vil være utfordrende å oppnå status som karbonnegativ på grunn av manglende loggføring av byggematerialer. Andre alternative statuser for bygget kan oppnås ved å finne en balanse mellom forbruk og produksjon. Hovedbygningen brukte 175 kWh/m^2/år i 2021. For å kunne kategoriseres som et plusshus må forbruket reduseres til 90 kWh/m^2/år, mens TEK17-standarden er på 125 kWh/m^2/år. Forbruket bestemmer mengden overskuddsenergi og dermed hvor mye energi som kan lagres. For å bli selvforskynt med energi må bygningen redusere forbruket med 68.8%, basert på hydrogensystemets effektivitet. Gitt overbelastningen av nettet i Kirkenes, vil den mest gunstige tilnærmingen være en hybridløsning av lagring og salg av overskuddsenergi. Dette vil også gjøre det mulig å kjøpe energien tilbake i perioder med lav produksjon.

Oppgaven konkluderer med at det vil være mulig å produsere tilstrekkelig med energi gjennom sol- og vindkraft til å drive hovedbygget i Nothing Hill prosjektet. Av de ulike lagringsalternativene er hydrogen best egnet, men lagringstanken viste seg å måtte være meget stor, og et samarbeid med strømnettet kreves for å være selvforsynt året rundt. Selv om bygningen sannsynligvis ikke vil oppnå status som karbonnegativ, vil den kunne kvalifisere som et plusshus hvis energiforbruket reduseres, samt at varmebehovet dekkes av geotermisk energi.

Contents

List of Figures

List of Tables

Symbols and abbreviations

Symbols

Symbol	Unit	Elaboration
η	%	Efficiency
Gt	W/m^2	Solar irradiation
β	°	Declination angle
E$_{pv}$	kWh	Energy delivered by a PV module
P	W	Power
E^0	V	Cell potential
Δ Hr	J	Enthalpy in certain reaction
Δ G	kJ	Gibbs free energy
Δ Sr	J K^{-1}	Entropy in certain reaction

Abbreviations

Term	**Definition**
PV	Photovoltaic
EU	European Union
UN	United Nations
NOCT	Nominal Operating Cell Temperature
STC	Standard Test Conditions
TES	Thermal Energy Storage
DC	Direct Current
PEM	Polymer Electrolyte Membrane
PEMFC	Polymer Electrolyte Membrane Fuel Cell
AEM	Anion Exchange Membrane
HHV	Higher Heating Value
LHV	Lower Heating Value
MEAs	Membrane Electrode Assemblies
CCM	Catalyst Coated Membrane
PGM	Platinum Group Metals
FCEV	Fuel Cell Electric Vehicle
HFCV	Hydrogen Fuel Cell Vehicle
NOK	Norwegian Krone
USD	United States Dollar
LCA	Life Cycle Analysis

1 Introduction

The Arctic region in Norway has been influenced by several negative factors in the recent years. This has resulted in a somewhat negative development called ”the Triple-Crisis”. Urbanization has caused the population in these areas to gradually decrease, and with the recent corona pandemic as well as the Russian invasion, the situation has become even worse. Sør-Varanger has been one of the areas hardest hit by the crisis in northern Norway, with a net migration of -72 people in 2022 [47]. In the center of Sør-Varanger municipality lies the town of Kirkenes. In addition to the negative population development, the tourism industry, which accounted for 500 workplaces, was embellished due to the recent pandemic. Since the second world war, Russia has been the main trading partner for Kirkenes. The Russian invasion in Ukraine in February 2022 created a complete stop in the shipping, tourism, and mining industry in the Kirkenes area, affecting the situation for the worse. High North Development group has therefore chosen to start a project called the Nothing Hill project, to challenge and dispel the negative prejudices associated with the area.

1.1 The Nothing Hill project

The Nothing Hill project started in 2021 and is one of the most important prospects concerning the Arctic region. The project is an interplay between several companies with a main goal to reform an old hospital, as well as 160 accommodations located in the city of Kirkenes, to a venue and a modern student campus. The project will contribute to the further development of the area, and the finished product will stand out as an example of modern construction with future-proof employment and engineering as the main characteristics.

The hospital will be replaced by a new modern student innovation campus. The whole area is going to be completely self-served by green energy, and aims to be labeled as a carbon-neutral village. The main building contains 22 000 m^2 of space. This building will be the standout construction for the village and become the student innovation campus. In the basement, the main focus will be entrepreneurship. It consists of an area of 5200 m^2 and will be designed to be an innovation cluster with lab areas, and research facilities for companies to develop and pilot different new projects. This will be an entrepreneurship and innovation floor, a first-class co-working area with meeting rooms, offices, and conference spaces. The first and second floors of the campus will be dedicated to education, with a target to develop one of the world's best educational systems. The third floor is planned to be the area for entertainment, which will be an important element of the campus. The facilities at Nothing Hill will offer its inhabitants services that create a strong work/life balance. Everything from spa facilities, gyms, wellness, game rooms, restaurants, bar, and other facilities that makes people happy and empowered.

The Nothing Hill project is huge seen from the outside, with several different aspects. The main purpose is to restore and make the old hospital self-served, with an energy production higher than the consumption. If this criteria is fulfilled, the building can go under the designation of a *positive energy building.* The excess energy can be either be stored using appropriate storage methods or sold to the grid. In order to become a carbon-negative village it is necessary to take all the energy and emissions used in the building process, renovation, and demolition into the calculations. If then the building/village is still producing more green credits from renewable sources through its lifetime, it can be called carbon negative. Transitioning to renewable energy sources is a significant step to reduce emissions in the area. Additionally, utilizing recycled materials, adopting sustainable practices, and decreasing the usage of fossil fuels are all crucial components of this effort. It is worth noting that achieving these goals is a long-term process and cannot be accomplished overnight. [69]

1.2 The objectives of this thesis

The Nothing Hill project is in the start-up phase and many things must fall into place to reach the goals. An excursion to the location was done to achieve as reliable information as possible for further investigations. To be able to complete this report, it was necessary to make system boundaries and narrow down the scope of the problem. The title of this bachelor thesis is *Use of renewable energy and hydrogen storage for a carbon-negative village*, and the main objectives are:

- **To measure the potential energy production through solar and wind sources in the Nothing Hill project**
- **To examine the possibility of using hydrogen as a storage method in comparison to other available alternatives**
- **To evaluate the energy budget to ensure year-round availability with self-served energy**

2 Background

The focus on a sustainable way of living and ”making the world a greener place” has been around for quite some time now, since the way of thought changed drastically around the 1980s. Before this, the usage of oil and coal was not considered negative, and huge machines and manufacturers released extreme amounts of climate gasses into the atmosphere. As seen in figure 2.1, the world's average temperature started to increase shortly after the industrial revolution. The idea that humans affected this was way back in peoples' minds, but the realization became more real as the climate drastically changed.

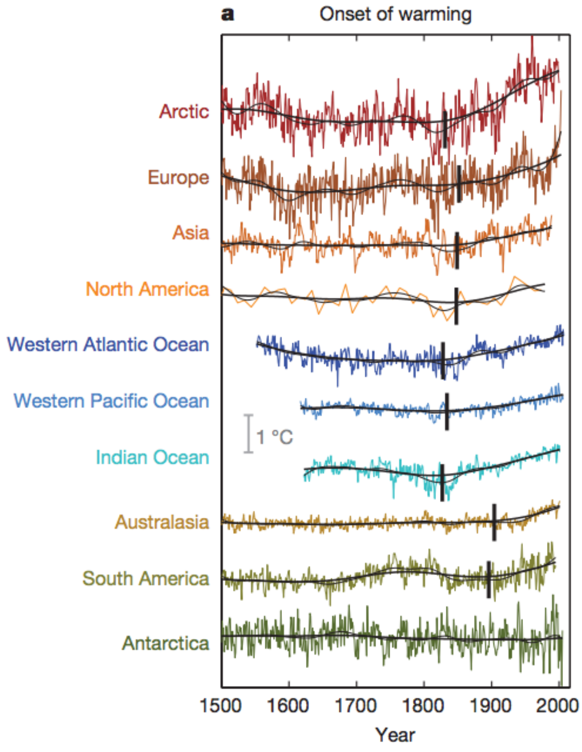
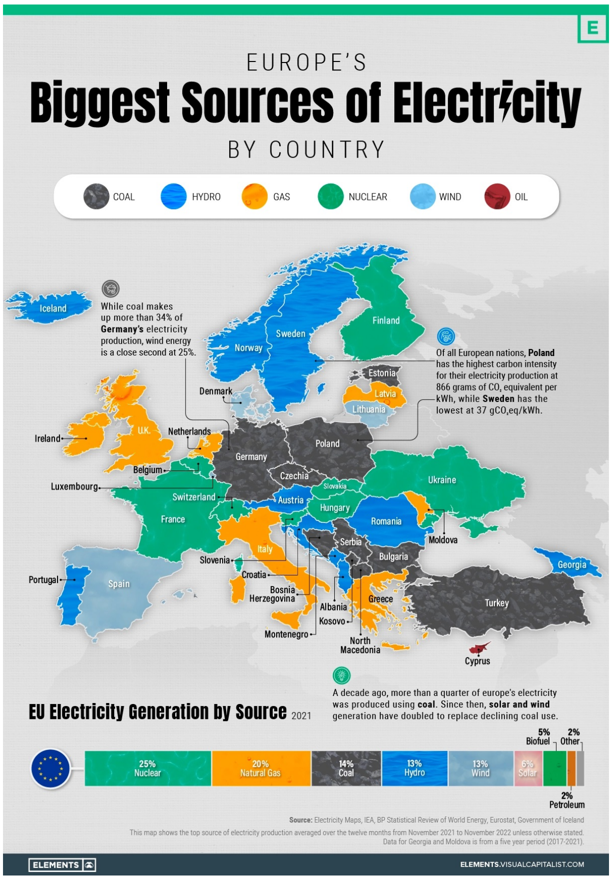


Figure 2.1: Development of the temperature around the world [75]

A turning point in this way of thought was introduced by an agreement called ”the Brundtland Commission”. It was founded in 1983 as a sub-group of the UN, and the main goal was to unite countries in the pursuit of sustainable development [9]. After this agreement, there have been frequent meetings between big parties with climate being the main topic. In the climate session, there have been three main agreements through the last three decades. This started in Rio in 1992 at the UN conference with the climate convention, where the first agreement to prevent dangerous human-made climate changes was made. This is still being used today and gives the industrialized countries more responsibility than the developing countries. However, no quantified obligations for either were decided. Five years later the Koyoto-protocol was founded. This was an agreement that confirmed that the industrialized countries must reduce the emissions of greenhouse gases by at least five percent during the 2008-2012 period. In 2015 the biggest and most important deal was made, the Paris-agreement. Here there were both individual goals for each country to fulfill and for the entire world to cooperate on. The main goal was to limit the temperature rise to a maximum of 1,5 °C. In addition, the goal was that the world must be climate-neutral before the second half of this decade. When it comes to our country, Norway has agreed to reduce the emissions from climate gases by 50-55 % by 2030. This will require a drastic change in the way of living. [58]

There have been many ideas on how to reach the goals set in the agreements and how to change the negative trends into more sustainable ways of living. The most important one is the change from fossil fuels to energy generated through renewable sources and nuclear power. The electrification of cars, industry, and heating are huge factors in this transition. However, the background of the used electricity is also important to consider. If the electricity is produced through fossil fuels the affection is not as climate-friendly as first thought. Therefore energy production must be done in a sustainable way.

Figure 2.2 shows the main sources of electricity production in countries in Europe in 2021. The largest sources are nuclear energy and natural gas [14]. The electrification of the society causes a huge increase in demand for electricity. To reach the sustainability goals, the electricity share of the total energy consumption is predicted to increase from 20 % today to 30 % in 2030. This requires an increase in clean power generation by 3 times before 2030 [11]. This increase in demand for electricity must be a result of sustainable energy production. As many renewable sources as possible have to be utilized to ensure minimal negative impacts on nature and society. [11]



While coal makes up more than 34% of **Germany's** electricity production, wind energy is a close second at 25%.

Of all European nations, **Poland** has the highest carbon intensity for their electricity production at 866 grams of CO_2 equivalent per kWh, while **Sweden** has the lowest at 37 gCO_2eq/kWh.

A decade ago, more than a quarter of europe's electricity was produced using **coal**. Since then, **solar and wind** generation have doubled to replace declining coal use.

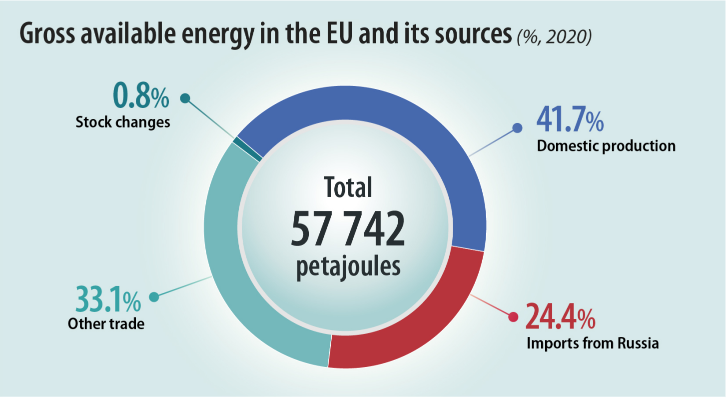
Source: Electricity Maps, IEA, BP Statistical Review of World Energy, Eurostat, Government of Iceland

This map shows the top source of electricity production averaged over the twelve months from November 2021 to November 2022 unless otherwise stated. Data for Georgia and Moldova is from a five year period (2017-2021).

Figure 2.2: European countries' biggest sources of electricity [14]

2.1 Energy crisis

Figure 2.2 shows that most of the electricity produced in Norway comes from hydropower, with a production rate of 95%. This is only possible because of the Norwegian scenery. With the help of a unique landscape composed of high hills and deep valleys, hydro-stations can be implemented at a higher density and with higher potential. This allows a high electricity production. Therefore, Norway is able to be self-served with electricity. However, this is not the case for every country in Europe. Figure 2.3 shows the importance of importing energy into the European energy system. The dependence on other countries' production is significant. In total, 58 % of the energy used was imported in 2020. Russia supplied 24 % of this mainly produced from natural gas. On the 24. of February 2022, Russia invaded Ukraine. This caused chaos in all markets with sanctions towards Russia intentionally affecting their economy and weakening their situation. The invasion is aggravating a global food crisis with significantly less export of food to developing countries. The mobility to travel is highly affected by closed airspace and additionally, the energy market in Europe is under-supplied.



ec.europa.eu/eurostat

Figure 2.3: Energy consumption and production in Europe [71]

Between the day of the invasion and 31. of July 2022 the European gas and electricity wholesale prices increased by 115 % and 237 % respectively [73]. This caused the EU to adopt an emergency regulation on 6. October with the main points being "reducing electricity use", "capping revenues of electricity producers" and "securing a solidarity contribution from fossil fuel businesses". With all these points in mind, the focus on energy supply, production, and efficiency exploded. [39]

In Norway, the power market is divided into five different regions based on geographical location. Within these areas the generation and consumption of energy are different. More people live in southern Norway without the certainty of higher production. This creates price differences. In addition, two new power cables were produced in 2021 to help Europe become self-provided with energy. A possible way to avoid the high prices, reduce the load on the grid, and at the same time reduce emissions, is to implement micrograds. [48]

2.2 Microgrids

A microgrid is defined by Elisa Wood, co-founder of Microgrid Knowledge, to be *a self-sufficient energy system that serves a discrete geographic footprint* [81]. This is an enclosed system that can include energy production methods, storage possibilities, and distribution without the necessity to be connected to the grid. Most of the industries and buildings today are connected to a bigger grid with energy provided by companies where the prices as mentioned in chapter 2.1 vary greatly. With a self-served system, the energy will be produced locally. This removes the transmission losses that occur during the transportation of the electricity from production sites to the user. These issues can be up to 8 - 15 %. A microgrid is still often connected to a central grid, but it can disconnect at any time and go into "island mode". With modern and advanced technology this connection makes

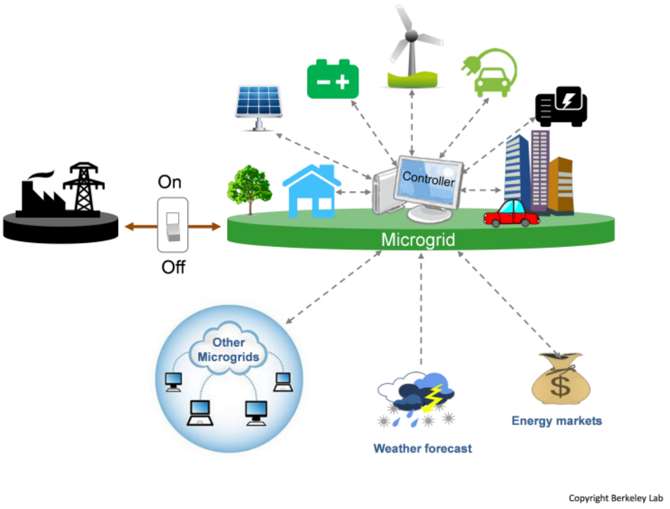


Figure 2.4: An example of the interplay in a microgrid [57]

the smaller system able to meet the energy goals in the best possible way. With algorithms programmed by the customers, the grid can buy energy from the central grid when the prices are low and rather charge up the batteries from the energy produced. [81]

Numbers from 2020 show that almost 80% of the installed capacity in microgrids was powered by fossil-fuel mechanisms, making the definition of a microgrid a bit uncertain. To define the system for this project, a microgrid can only be defined as green when powered by renewable sources. Figure 2.4 shows an example of how a "green" microgrid works. The main parts of the production are usually solar and wind energy. The implementation of new technology gives in addition the advantage to utilize other more modern sources, such as geothermal and wave power. In 2019 the rated global microgrid capacity was 3 480 MW, but it was expected to increase to 19 900 MW by 2028 [81]. High North Development Group hopes to increase this number by renewing the old hospital in Kirkenes, making it into a self-served microgrid. [81]

2.3 Kirkenes

Kirkenes is a relatively small town located in Finnmark county, in the northern part of Norway. The location is shown in figure 2.5a, with a more detailed overview of the town in figure 2.5b.

(a) Kirkenes' location in Norway [44]

(b) Detailed map of the town [29]

Figure 2.5: Map of Kirkenes, Norway

Kirkenes is labeled as the administrate center of Sør-Varanger municipality and is the 112^{th} most populous municipality in Norway with a population of 9850 people. Kirkenes itself has an area of 2,3 km^2 and a population of 3383 people. Most of these inhabitants live in the city center and urban areas around the city center such as Hesseng and Bjørnevatn. The majority of the inhabitants are of Norwegian heritage, with a minority being Sami, along with a small percentage of immigrants from Finland and Russia. Due to its location near the Russian border, Kirkenes has been influenced by both Norwegian and Russian cultures. [6]

Kirkenes has certain distinctive features that also make it an attractive destination for tourists. A visit to Kirkenes is a great opportunity for people interested in experiencing the unique culture and natural beauty of the region. One of the most attractive features of the city is the opportunity to see the Northern Lights. Because of its location by the Arctic Circle, Kirkenes is one of the best places in the world to view this spectacular natural phenomenon. In addition to the Northern Lights, there are other arranged tourist activities in the city, including dog sledding, king crab safari, and snowmobiling. Tourism is important in Kirkenes. It has traditionally been a significant factor for the city, and will continue to play an important role in the future with the city also being the last stop on the popular coastal cruiser Hurtigruten. [45]

As a part of improving the economy and reputation of Kirkenes, the shipping department may be worth targeting. Each day large amounts of goods are shipped worldwide, and a high percentage comes from China. These ships travel a sea route currently passing through the Suez Canal. However, by rather traveling through the Northern sea route the total travel distance could be shortened to 40 %. This is shown in figure 2.6, where the red route represents the Northern sea route and the blue line is the existing shipping route.

Figure 2.6: The Northern sea route in comparison to the existing route [77]

2.4 The project

By focusing on development within engineering and entrepreneurship, the expectation is to turn Kirkenes into a more popular place to live, study and work. The previously mentioned triple-crisis will need a solution, which will be in the form of a created triple-E-model shown in figure 2.7. The three E's represent Entrepreneurship, Education, and Entertainment, and are the three main focus areas for the project. High North Development Group has decided to specifically focus on these points. As a result, they started the Nothing Hill project.

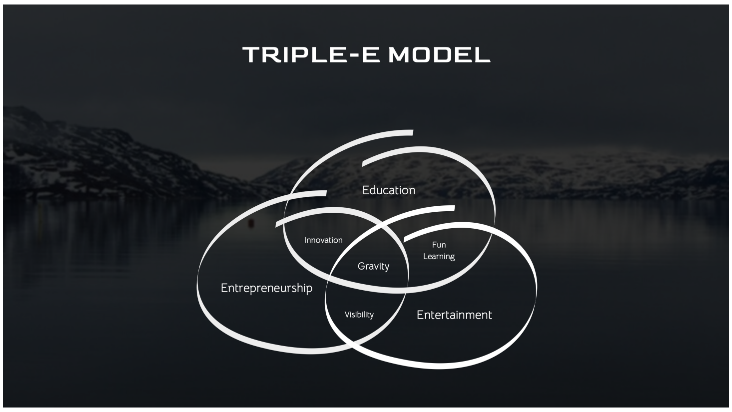


Figure 2.7: The Triple-E model

The project is based on the ArcTech model, which is described as the needed solutions that shape the future, in and from the Arctic. ArcTech covers global solutions fueled by tech that are implemented or created in the Arctic. The challenges that the region faces are similar to other rural areas, but the Arctic area has different capabilities for creating, testing, and exporting solutions. The aim is to create a strong ecosystem of ArcTech companies, organizations, and research to tackle the problems of the Arctic and the rest of the world.

The ArcTech model is aligned with the Norwegian Arctic Policy key points which are:

- Taking a broad-based approach to climate change and the environment in the Arctic
- Working towards the UN Sustainable Development Goals
- Promoting job creation and value creation
- Being at the forefront of technological development
- Highlighting the benefits of cooperation

The old hospital, shown in figure 2.8, located on top of the peninsula Prestøya in Kirkenes, will be replaced by a brand new student innovation campus. Co-living, co-learning, and co-working are three stand-out terms that describe the innovation campus. An additional floor is planned to be built to develop Nothing Hill into a unique event space in the Nothingness that can cater to large-scale events, conferences, and corporate off-sites. The idea is to turn the top floors into a modern, vibrant, and affordable co-living concept. Co-living is a concept that enables short and long-term stays. It will maximize space, while still keeping the cost low for the inhabitants. The co-learning platform is described as a key solution for the seamless development and implementation of educational programs, where it will be possible to establish everything from satellite campuses to different summer courses. The goal for the population in Kirkenes is to consist of 20 % of students. [33]

The goal for the campus is to be in an energy surplus or be defined as carbon neutral by the end of the project. All of the areas require a certain amount of energy to function as desired, and all of this energy needs to be produced within the area of the village. In an energy-positive village, nothing is left to chance. Every little part of the village needs to be optimized to be able to profit energy-wise over a whole year. Old and outdated energy boilers will be replaced by a brand new energy center consisting of five co-operating renewable energy sources. The purpose is that renewable energy will be produced, stored, and used in a symbiotic system 24 hours a day, 7 days a week, 365 days a year. The energy will be produced by several different green production methods, including solar, wind, and geothermic energy. Additionally, there must be figured out a way to utilize the waste heat from the different components, especially the data center. The main task is to calculate the maximum theoretical energy output from the solar cells and wind turbines, and then determine the storage potential with the use of appropriate energy-storing methods. The majority of renewable energy generated by wind and solar sources will be stored in the form of hydrogen, primarily due to the numerous benefits it offers to this specific project.

Figure 2.8: The old hospital

A system of hydrogen production can path the way for further development in terms of several areas of use and additional services. The hydrogen in the project will be produced close to the sea coast, within a distance of 100 meters. This makes seawater available for hydrogen production. In addition, it is possible to connect several other hydrogen projects in the area together. One possibility is to build hydrogen filling stations. This will allow the ships sailing the Northern sea route or other transport vehicles to refuel their tanks. One of these other similar programs is the Haeolus Project, close to Berlevåg. Here hydrogen is produced whenever Raggovidda Windpark produces more energy than consumed in the area. A refueling station was a part of the original offer that High North Development Group received, but this will certainly make an impact on the available energy during the winter season. If the produced hydrogen is planned to be sold or used in refueling stations, a deal should be made with other local contractors to ensure a year-round green energy-supply, and to work towards the title as a carbon negative-village.

An additional point of building energy-positive buildings is to show that it is possible to run buildings that are 100% based on energy from renewable sources this far north. Projects like Nothing Hill will contribute to the work to achieve the UN Sustainable Development Goals. It will also benefit from the fact of being at the forefront of technological development. Since Nothing Hill is a future-oriented project, it needs to be environmentally based, with the use of clean energy. Since energy-positive buildings generate more energy than they consume, it means that they can contribute to a reduction in carbon emissions by producing a surplus of clean energy on-site. This can help in the fight against climate change, which is caused mainly by carbon emissions from burning fossil fuels. Projects like Nothing Hill can therefore inspire others to take action and reduce their energy consumption.

3 Theory

This section gives an overview of the theory behind the energy-producing methods and storage options that are possible to use in this project. This will cover the most important aspects of the different methods, creating the foundation for the calculations done later on in the report.

3.1 Solar Energy

Solar energy is both renewable and reliable, but the efficiency of current methods has been constrained. Nonetheless, ongoing efforts are dedicated to optimizing technologies and expanding the utilization of this abundant energy source. A photovoltaic (PV) system is an efficient and versatile method of utilizing this potential. A PV system is composed of one or more solar panels and works on both larger and smaller scales. Together with an inverter and other electric components, the solar panels can generate electricity whenever the sun is shining. Solar cell technologies are constantly developing, and panels are gradually becoming cheaper. This makes them more accessible and affordable to ordinary households and means investing in a PV system now is much more realistic than before. In addition, they are even more beneficial on a larger scale. Several components affect the total energy produced from a PV system, such as the azimuth angle, tilt angle, location, and the amount of shade covering the panels. To calculate the total amount of energy the panels can produce, all of these factors must be considered. [62]

3.1.1 Efficiency and optimization

When deciding whether it's worth investing in a power plant of PV panels, and where to build it, certain factors need to be considered, and a range of effects in addition to temperature losses. For locations north of the equator the proper panel orientation is facing true south. An azimuth angle of 0°means that the panels are always facing the equator, on the south side. This ensures that the cells will get the most out of the sun's energy because the sun always is located south. There are different ways to optimize the tilt angle. One option is to use a solar tracking system to have tilted panels, which will follow the movement of the sun to maximize energy production. This will give the highest energy output throughout a year. However, the technology required for this is more expensive than the alternative which is to have solar panels at a fixed tilt. The latter is the simplest method and is often preferred when placing the panels directly on roofs and walls of buildings because it is an easier and more cost-effective approach. If a fixed tilt angle is used, the angle needs to be calculated in such a way that it takes greater advantage of the summer months when the sun produces more flux and is higher in the sky. [68, 67]

The location of the panels also has a large impact on their effectiveness. The solar panel efficiency is determined by tests at STC. These include a cell temperature of 25°C and an irradiance of 1000 W/m^2. Based on the standard conditions it is possible to calculate the performance of different solar panels on the back of their specifications.

3.1.2 Temperature correction

The performance of a PV module depends on the cell temperature. Solar cells generally perform better at lower temperatures, which means that it is possible to have solar cells working at even higher efficiency than at standard conditions. This is because an increase in temperature also causes the resistance of the material to increase. The loss of efficiency when there is an increase in temperature varies between different cells from different manufacturers. An example of a typical temperature coefficient value for mono-crystalline cells is -0.5%/°C. This means that the cell will loose half of one percent of its power for every degree the temperature rises. For the solar cells used in this project, the temperature coefficient is -0.35%/°C, which indicates higher quality solar panels. The panels obtain their highest possible efficiency at a temperature of -5 °C, which then makes it possible to calculate the maximum efficiency operating point. [34]

It is possible to calculate the cell temperature by equation 3.1.[43]

$$T_{cell} = (T_{NOCT} - T_{a,NOCT}) \cdot \frac{Gt}{Gt_{NOCT}} \cdot (1 - \frac{\eta}{\tau a}) + T_a \tag{3.1}$$

The equation includes values of Gt_{NOCT} (the irradiation), and $T_{a,NOCT}$ (the ambient temperature), which are NOCT conditions and therefore set values. Gt_{NOCT} is 800 W/m^2 and $T_{a,NOCT}$ is 20 °C. T_{NOCT} is given in the specialization sheet for the relevant PV module. η represents the PV panel efficiency. The τa value for silicon cells is 0.90.

3.1.3 Snow and ground reflections

The amount of snow that covers and surrounds the panels will also make an impact on energy production. The solar cells will stop working when there is created a snow layer of more than 5 cm, as this will decrease the solar panel efficiency by 100 %. However, the panels during the winter months are tilted at a quite steep angle. This will help the snow to easier glide off the panels, and will therefore contribute positively should there be potential snow problems. Even though an overflow of snow in one way may inhibit the desired energy production, snow will also reflect sunlight on the panels. This is called the albedo effect, which could significantly increase the efficiency and therefore the energy output of the cells. Solar cells can capture a large amount of sunlight including ground reflections if the model used is so-called bifacial, as shown in figure 3.1. Since snow can reflect up to 90 % of the sunlight this will make the albedo number significant. [35]

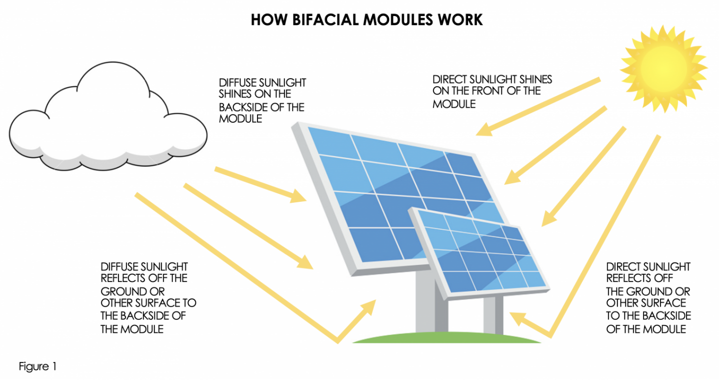


Figure 3.1: How bifacial panels and the albedo effect affect the production [8]

3.1.4 Shading

Other than the albedo effect and the increased panel efficiency in colder climates, the shading factor is another important element to consider. When PV modules are tilted there is a risk that they may shade each other. The solar panels must be placed and orientated in such a way that makes sure that the amount of shade they get during the producing hours is as little as possible.

The optimal amount of shading is influenced by several variables such as costs, electricity, irradiation, and surrounding topography. The shading factor becomes more significant whenever the sun is low in the sky, as this increases the shadow length as shown in figure 3.2. To avoid shading completely the distance between the modules therefore needs to be quite large. However, it is not necessarily the best choice to eliminate shading, as higher panel efficiency will come at the expense of potentially having more producing panels. The key to success is therefore to find a module distance that will balance these two things. As an example, shading is most severe during the winter, however, there is less irradiation which makes the factor virtually insignificant.

It is well known that tilting maximizes energy yield per area of the module. However, this generally requires greater spacing which can lead to a decrease in energy yield per area of land. This is because the greater yield obtained from tilting and tracking panels could be outweighed by the spacing. This also depends on the price of the modules as well as the price of the land.

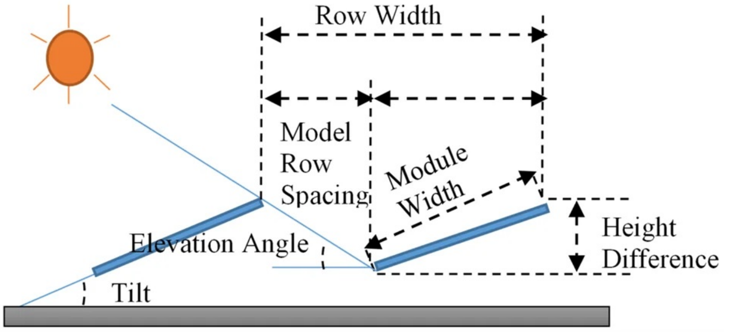


Figure 3.2: It is important to choose the right distance between the panels to avoid self-shading [41]

Snow, ground reflections, and shading are therefore all important factors that must be taken into account when dimensioning solar cell systems at a certain location.

3.1.5 Tracked solar panels

To find the optimal surface tilt angle every hour for a tracking solar panel system one must take several steps. Firstly, the angle of declination needs to be calculated, an angle depending on the current day of the year of the calculation.

Table 3.1: Day number in a year

Month	Day Number
January	i
February	31 + i
March	59 + i
April	90 + i
May	120 + i
June	151 + i
July	181 + i
August	212 + i
September	242 + i
October	273 + i
November	304 + i
December	334 + i

The declination angle is given in equation 3.2.

$$\beta = 23.45 \cdot sin(\frac{360}{365} \cdot (284 + N)) \tag{3.2}$$

Where N is the day number obtained from table 3.1. The next step is to find the altitude angle α, and then use this to calculate the tilt angle. The equation for the altitude angle is given in 3.3.

$$\alpha = \arcsin(\sin L \sin \delta + \cos L \cos \delta \cos h) \tag{3.3}$$

L is the local latitude, and h is the hour angle. At local solar noon, the hour angle is 0, which means that $\cos h = 1$. At any other local time, one needs to find the apparent standard time, AST, to find the hour angle. The hour angle is then calculated from equation 3.4.

$$h = (AST - 12) \cdot 15 \tag{3.4}$$

The next step is to use all the parameters in equation 3.3, to obtain the altitude angle, and the tilt angle is then simply $90° - \alpha$.

This method makes it possible to find every optimal angle for every date and time of the year. It is then possible to program the panels to adjust every hour to maximize power production.

The yield benefit of tilting increases thus further north in the world the panels are placed. This is because of the low sun in the sky. At the latitude of 65 degrees north, the output can increase by 35 % if the panels track the sun compared to panels with a fixed angle. At the same time, there are potential issues with this strategy in the form of shading between the panels, which means the panels have to be placed further apart and take up more space. The construction of this setup could also be problematic, with a motor that needs to be changed when broken. The panels are also more exposed to wind and other extreme weather conditions. [43]

3.1.6 Fixed solar panels

In most cases, the angle of the solar cells will be in a fixed position. The optimal fixed angle must therefore be the angle that maximizes the yearly energy output of the solar panels. The angle is based on the whole year with a weight towards the summer months when the energy production is the highest. To find the optimal fixed angle for a location, two different equations are used. Equation 3.5 is used to find the best angle for locations with a latitude smaller than 65°, while equation 3.6 fits for locations with a latitude larger than 65°.

$$Tilt = 0.764 \cdot L + 2.14^{\circ} \tag{3.5}$$

$$Tilt = 0.224 \cdot L + 33.65^{\circ} \tag{3.6}$$

These equations are modified to maximize the annual yield from a solar panel. It also takes into consideration that the irradiation in the summer is much higher than in the winter.

3.1.7 Energy produced from the solar panels

The energy delivered from a PV array can be found in equation 3.7. [43]

$$E_{pv} = \eta \cdot A \cdot Gt_{average} \tag{3.7}$$

The efficiency is given for different solar panels, but it varies as mentioned in the earlier chapters. To find the efficiency with the temperature correction equation 3.8 was used.

$$\eta_{new} = \eta_{old} + K \cdot (25℃ - T_{celle}) \tag{3.8}$$

K is the temperature coefficient for the power given by the producers of the solar panels. The next step is to find Gt, which is the annual solar radiation. This number can be found in different meteorological sites.

3.1.8 Solar potential in Kirkenes

Kirkenes is a small town located far north in Norway, and are specified by a local latitude of 69.73 N and a longitude of 30.05 E. Further information is given in table 3.2.

Table 3.2: Location information

Geographical site	**Latitude**	**Longitude**	**Altitude**	**Time zone**
Kirkenes, Norway	69.73 N	30.05 E	24 m	UTC +2

The yearly global irradiation data for Kirkenes is given in table 3.3. Global irradiation is the sum of diffuse and direct solar radiation. Some of the sunlight passing through the atmosphere will be absorbed, reflected, and scattered by different particles. This is defined as diffuse solar radiation. The sunlight reaching the earth without being diffused is classified as direct solar radiation. The solar spectrum is different in northern cities compared to the southern ones. This is because the particles from the sun get weakened through the atmosphere before reaching the surface of the earth. Combined with the fact that the distance through the atmosphere is larger in the polar regions compared to at the equator, this results in less energy. In the northern parts of Norway, diffuse radiation makes up the largest part of global irradiation, and the amount of diffuse radiation is also greater than in southern areas. Since diffuse radiation has a short waved spectral distribution it is beneficial to use solar cells with a technology that captures more of the red light and are more effective at shorter wavelengths. One solution to this is to use cells with PERC technology, which are able to reflect some of the longer waved light to the backside of the panels and make them available for absorption. As long as the panels are intended to be mounted separately, it is an appropriate solution to use bifacial panels. These panels are covered with glass on both sides to be able to reflect as much sunlight as possible. This will increase energy production as the panels can exploit more of the total irradiation. [5].

Since Kirkenes is one of the northernmost cities in the world, the amount of solar radiation varies greatly between summer and winter. As seen in the data in figures 3.3 and 3.4, there will be very small amounts of total sunlight during the winter months, and a significantly greater amount during the summer. This is due to the earth's position and rotation. The earth is rotating at a tilted axis of 23,45 degrees, and because the north pole is tilted towards the sun during the summer month this means that more of the sun's rays hit than at any other time of the year. The amount of daily sunlight during the summer combined with the fact that solar cells perform better at low temperatures, therefore makes Kirkenes a favorable location for solar energy production.

Table 3.3: Global horizontal irradiation data for Kirkenes [56]

	Global horizontal irradiation (kWh/m^2)
January	0.0
February	10.0
March	50.1
April	107.1
May	136.2
June	139.8
July	127.1
August	87.5
September	44.8
October	15.6
November	1.5
December	0.0
Total	719.7

The irradiation data used for the calculations are obtained from the database Meteonorm 8.1 which is able to provide accurate results and simulations based on a large number of weather stations around the world. [56]

Table 3.4: Global irradiation data for Kirkenes [56]

	Global irradiance in Kirkenes (W/m^2)
January	0,0
February	14,9
March	67,3
April	148,7
May	183,1
June	194,2
July	170,8
August	117,6
September	62,2
October	21,0
November	2,1
December	0,0

3.2 Wind Energy

The utilization of wind to produce energy is also a very known method within the renewable energy industry. In short terms, the usage of the wind's kinetic energy makes the rotor spin a generator to produce electricity. It is a highly discussed topic in today's society because of the negative sides of production, mainly the effects on the environment. Is it a sustainable production method considering birds fly into the blades at high speed, and does the concrete mass of the structure destroy huge grazing areas for reindeer and other animals? Because of these negative topics, the focus on smaller turbines to place on rooftops and other locations has increased drastically over the past few years. These have a lower production capacity, however, the energy goes directly to the building or small community. To calculate the amount of energy produced, the wind speed throughout the year is the most important factor, and the calculations are based on the rated power for the turbine. [80]

3.2.1 Possibilities in Kirkenes

When evaluating the potential of wind energy in Kirkenes several factors must be taken into consideration. The average temperature in this area is close to zero throughout the year so the turbine needs to be able to produce electricity during cold conditions as ice and snow may appear as a problem. Additionally, Kirkenes is located near the ocean, resulting in higher average wind speeds compared to inland areas. Therefore the need for a robust turbine is immaculate due to the harsh weather conditions.

For most accurate calculations of energy production in this project, the local wind speed at the specific location is important. To figure out the best-suited location for the turbines, a test with certain wind speed tools can be done practically to find the best location to place the turbines. Additionally, data from local weather stations can give valuable information on the conditions in this area.

Table 3.5: Hours of different wind speeds in a year [60]

Wind speed (m/s)	**Hours of wind (average 2020-2022)**
0 - 2,5	1837
2,5 - 3,5	1322
3,5 - 4,5	1302
4,5 - 5,5	1109
5,5 - 6,5	951
6,5 - 7,5	757
7,5 - 8,5	561
8,5 - 9,5	428
9,5 - 10,5	248
10,5 - 11,5	136
11,5 - 12,5	63
12,5 - 13,5	25
>13,5	21

In table 3.5 the average speed for each interval of wind is presented. The data is based on the average wind speed in Kirkenes over the last three years [60]. The data used for the calculations presented in this report are from table 3.5. However, more specific wind speed data can be collected using an anemometer.

3.2.2 Output from wind turbines

To calculate the possible energy output from a turbine, the wind speed for each hour is divided into ranges between 0 m/s and 25 m/s. This is because each turbine has different operating wind speeds, and the output of each wind speed does not increase linearly, but rather exponentially. It is therefore important to gather accurate data for each hour of the day to know how much electricity these turbines can generate at any time.

The cut-in wind speed is the minimum wind speed required for a wind turbine to start operating and producing electricity. When the wind speed is higher than the cut-in speed, the blades of the turbine start spinning and the turbine starts generating power. As one can see, the power output increases with the cube of the wind speed until the wind speed reaches the nominal speed. At this point, the control system of the turbine modifies the pitch of the blades so that the power produced is constant at nominal power. When the wind speed exceeds the cut-out wind speed, the wind turbine will shut down to prevent damage to the turbine and ensure safety. When this happens, the turbine's control system will activate the brake mechanism to stop the blades from rotating. [64]

The power curve depicts the theoretical power generation potential of the particular turbine at varying wind speeds. The cut in wind speed for the model RW500 is seen in figure 3.3 to be 2,5 m/s. The figure proves that the turbine is able to handle wind speeds up to 60 m/s. The operating window is therefore large for this model. The rated wind speed is 10 m/s, and the rated power is 500 W with a maximum power of 3000 W for each turbine. With the turbines being only 2,2 m these are powerful numbers.

To calculate how much energy one wind turbine can produce, equation 3.9 is used.

$$E = P \cdot h \tag{3.9}$$

The total energy output is the power output at a certain wind speed, times the operating hours of this wind speed, in a certain interval. The power output for each wind speed interval is based on information about the specific turbine, which can be seen in a specification sheet.

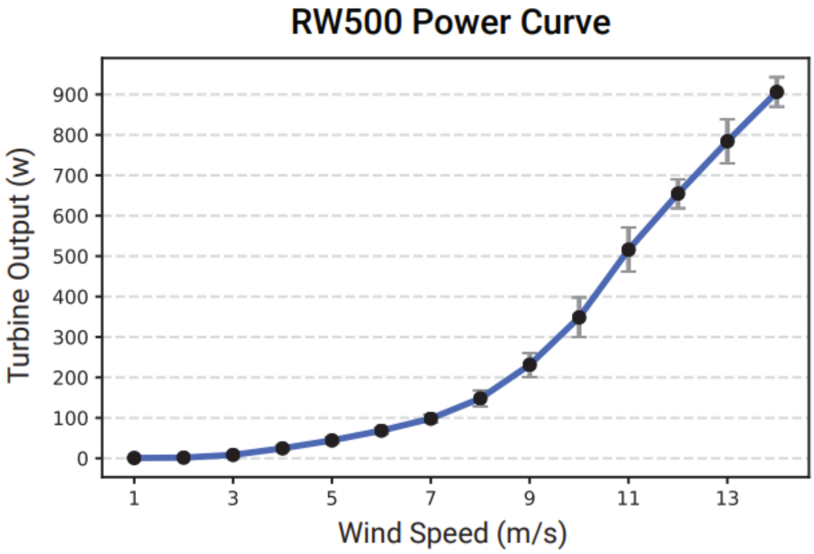


Figure 3.3: Power curve for the turbine B

Figure 3.3 shows the power output plotted against the wind speed for the specific turbine. The power output is calculated for each wind speed based on the information from the power curve in figure 3.3. This number is multiplied by the average wind speed for the location.

3.3 Storage and distribution

Due to the mismatch between renewable energy production and energy demand during the year, there will exist periods of overgeneration as well as undergeneration of energy. In the Nothing Hill project, energy will be produced primarily in the summer. In an electricity system where energy sources like sun and wind play a significant role, energy storage is an important factor in a successful grid system. This interplay of energy storage and production in a small scaled system can be connected to a grid, and make it possible to buy or sell energy [30]. The energy production from solar cells and wind turbines is unpredictable as one can not be sure when the sun will shine or the wind will blow. Energy storage will help to provide a continuous flow of electricity, and will secure electricity supply during periods of low energy production because there is energy stored in the grid. There will be close to no solar energy production during the winter, which means that one has to rely on other energy sources, in addition to the stored energy, during this period.

3.3.1 Different storage possibilities

Every different storage method has its strengths and weaknesses. To determine the best storage option for a certain project, it is necessary to consider the circumstances and purpose of storing the energy. One task is to calculate how much of the produced energy from renewable sources that needs to be stored to be able to get through the winter months. For situations like this project, where the energy needs to be stored for months, it is therefore beneficial to use a storage method that allows the energy to be stored for as long time as possible. Potential solutions within this field include:

- Thermal storage (TES)
- Lithium-ion battery
- Flow batteries
- Hydrogen
    - Compressed
    - Cryogenic

For this project, hydrogen energy storage will be the main storage element. In addition, a large amount of the energy will be stored thermally through a waterborne heat system. Both of these storage methods bring benefits that can be exploited when combined. This will be further elaborated upon in the next section. The main focus point should, either way, be on finding the best possible way of storing all the energy through the winter season. When choosing this, the different options need to be compared, with both negative and positive sides taken into consideration.

3.3.2 Thermal storage and distribution

Thermal energy storage (TES) is a storage possibility where a material gains energy by increasing the temperature, with an example shown in figure 3.4. The methods are divided into sensible, latent, and thermo-chemical heating. The most developed of these three is sensible heat storage where the basic principle is to increase the temperature of a material through heating, and then to release the energy when needed. The most commonly used medium is water because of its energy density and availability, but this is highly situation-dependent. The time frame of the energy storage is a huge factor when the medium is chosen, and the two main classifications are short and long-term storage. The application is therefore the main part of deciding whether to include this kind of storage in the system. [63]

There are several advantages to TES compared to other storage possibilities. A TES system usually includes many different factors with both heat distribution and air-conditioning as the main goals. With the inclusion of this kind of storage, other heating possibilities are no longer needed. Several previous methods for the building in the project used fossil fuels to produce heat. Thus, the use of fossil fuels will decrease and the environmental impact will also do the same. If the chosen medium is water, there are many possible areas of use. Hot water is being used in several different forms, such as showering, washing, and room heating, but also the air-conditioning and cooling parts of the system are becoming more important parts of a way of living. In this project, the inclusion of TES is almost inevitable because of the already waterborne heating system in the old hospital and the surrounding buildings. This system is an important part of heat distribution and with modern technology, the system can be upgraded into using the excess heat and cooling devices into a combination of heating and cooling systems. With the old system being heated by fossil fuels, the project will use excess heat from the upcoming data center, cooking, sewage, and other components that release heat in the process. In this way, the system is becoming an eco-system with biomimicry as the main plan.

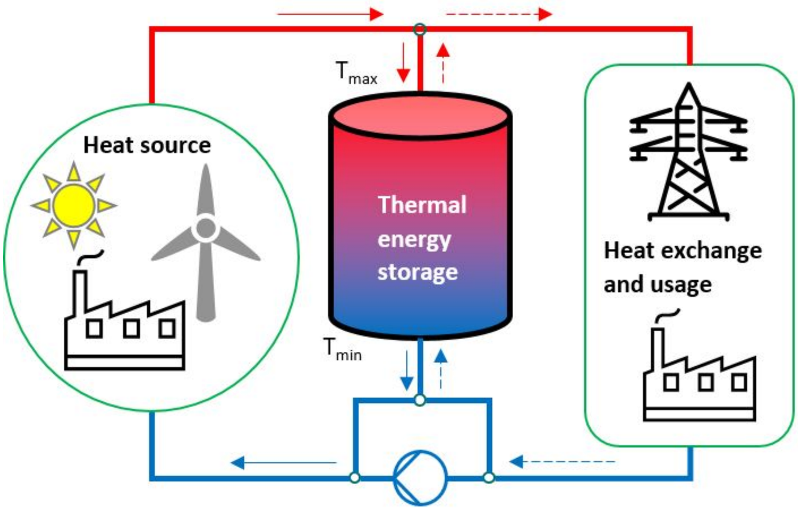


Figure 3.4: How a TES-system works [66]

3.3.3 Lithium-ion battery

The use of batteries is a common and well-known way to store energy. It is still a convenient option in many situations and is undoubtedly a great way to store clean energy. The battery industry has grown largely over the last few years with lithium-ion batteries at the forefront of the different battery technologies. The industry is expected to continue to grow in the future. From 2020 to 2021, large-scale battery storage systems in the United States tripled from 1,4 to 4,6 GW [15]. In Norway, 79,3 % of cars sold were electric, which makes up the highest percentage in the world [3]. Norway is therefore already a heavily invested country in the battery industry with companies such as Freyr, Morrow, and Beyonder having plans to build new large battery factories soon.

Batteries are great in terms of speed and flexibility. Unlike many other alternatives, batteries can respond fast to changes in solar or wind generation and keep the supply of energy stable. Batteries are also a great way of supplying additional power when the demand for energy peaks during the day, typically when a lot of machines are running at the same time. They also charge efficiently during the day and soak up the excess renewable energy whenever it is produced by the PV panels. [51]

Lithium-ion is the most popular rechargeable battery technology used today and is also the most used battery type for grid energy storage systems. They are lightweight and can repeat charging and discharging cycles thousands of times without losing significant capacity. Lithium-ion batteries use lithium-ions as the key part of their electrochemistry, as lithium is the cheapest and lightest chemical element. The battery consists of five components; an anode, a cathode, a separator, an electrolyte solution, and current collectors. The lithium ions move between the anode and cathode through a separator, which generates a flow of electrons that creates an electrical current. Li-ion batteries can use several different materials as electrodes, with the most common being the combination of cobalt oxide as the cathode and graphite as the anode.

When discharging, the positive ions move from the negative electrode which is the anode, to the positive electrode, the cathode. During charging the reverse process occurs, with the ions moving in the opposite direction. The half-cell reactions for a lithium-ion battery are given in equations 3.10 and 3.11, with the cell potentials of 1V and 3V respectively.

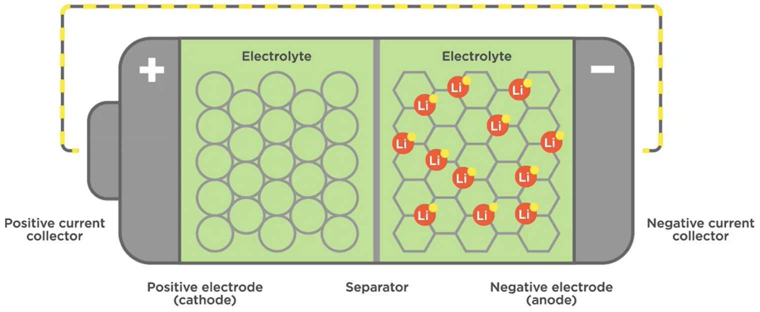


Figure 3.5: The components of a Li-ion battery [15]

$$CoO_2 + Li^+ \rightleftharpoons LiCoO_2 \tag{3.10}$$

$$Li^+ + C_6 + e^- \rightleftharpoons LiC_6 \tag{3.11}$$

The overall cell reaction is presented in equation 3.12. During discharge CoO_2 reacts with LiC_6 which makes the half-cell reaction in 3.11 move in the opposite direction, creating products of $LiCoO_2$ and C_6. This means that the cell potential E_0 can be calculated to 4V, as done in 3.13.

$$CoO_2 + LiC_6 \rightleftharpoons LiCoO_2 + C_6 \tag{3.12}$$

$$E_0 = E^+ - E^- = 1V - (-3V) = 4V \tag{3.13}$$

Several advantages come with the use of lithium-ion batteries. Li-ion batteries have one of the highest energy densities of today's batteries on the market, with a typical range between 100-265 Wh/kg. In comparison, lead acid batteries range from 50-100 Wh/kg which shows why li-ion batteries are a preferred option when high specific energy density is an important factor. Energy density is generally important because we can fit more energy into large devices which also means it is possible to have smaller functional batteries that don't require a lot of space. It also determines how long the battery can power a device and is critical when it comes to the safety of the battery. Li-ion batteries provide longer life cycles than most other batteries which means faster charging and lower operating costs.

This makes them suitable for electrical applications like mobile phones and electric vehicles. In 3.6 it is displayed how both the volumetric and the specific energy density of a li-ion battery compares to other popular batteries of today, and it becomes clear why it is considered as one of the best options on the market. [19].

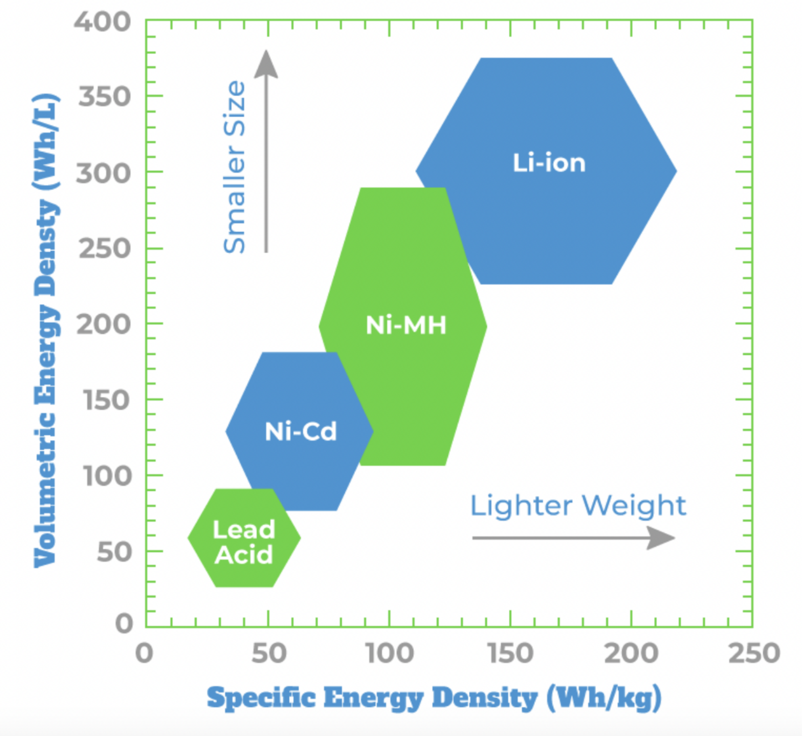


Figure 3.6: The energy density of a li-ion battery compared to other battery types [19]

Since lithium-ion batteries have a high energy density they also tend to overheat, and could therefore be damaged at high voltages. At a large scale, these batteries require safety mechanisms to limit the voltage and pressure on them, which again may come at the expense of increased weight and limited performance [54]. This is the main challenge with storing energy purely in Li-ion batteries, as one would have to make sure that the cell temperature is monitored properly to prevent temperature extremes. When installed on a large scale, a battery system also comes with quite high investment costs.

3.3.4 Flow batteries

A flow battery is a storage possibility where substances go through an electrochemical reaction to exploit the energy differences in the oxidation state [10]. This is the same definition as for the general description of batteries. However, in a flow battery, the substances are solutions kept outside the reaction cell and continuously fed into the system, rather than being coated on the electrode within the cell. Because of the placement of the materials, pumps are being used to circulate the two electrolytes around. The two solutions are separated by a thin membrane to avoid the two electrolytes to come into direct contact, as seen in figure 3.7. This membrane is usually a Proton Exchange Membrane and the material is most commonly Nafion or PFSA. This will prevent heat production and the spilling of usable energy. Therefore the membrane is an important part of the system, but often expensive. The basics are the same as in other battery types - when the battery is charged, one of the materials is oxidized and releases electrons, while the other is reduced and gains electrons. This process requires power and can be done with a connection to a power source such as a solar panel or wind turbine. When the battery is charged up and then used for exploiting energy, the components switch sides and energy is released by fetching the electrons that go from the anode to the cathode. [25]

The development and research around flow batteries is increasing, but at the moment the flow battery technology is said to be too expensive. With lithium-ion batteries being the most dominant in the market, the need for other technologies is increasing as lithium is not an unlimited source of material and is also highly flammable. Within the flow battery universe, the vanadium redox battery is the most developed technology. Here vanadium is used in both solutions based on the ability of the material to exist in four different oxidation states, so the battery does not have to use two or more materials. This makes the battery not being suffered from cross-contamination and so on degradation. The ions are mainly processed from dissolving vanadium pentoxide, V_2O_4, in sulfuric acid, H_2SO_4. The half-cell reaction for the positive electrode is presented in equation 3.14, and the negative electrode in equation 3.15, where the arrows indicate charging or discharging.

$$VO^{2+} + H_2O \rightleftharpoons VO_2^+ + 2H^+ + e^- \tag{3.14}$$

$$V^{3+} + e^- \rightleftharpoons V^{2+} \tag{3.15}$$

With half-cell potential of $1,0V$ for the reaction in 3.14 and $-0,26V$ for the reaction in 3.15, the OCV for a vanadium redox battery is rated between 1,15-1,55 V. This depends on the other substances involved as well as the operative conditions. This is quite high for a flow battery at this scale and gives the battery a specific energy between $10-20\frac{Wh}{kg}$. This is significantly lower than other technologies, such as lithium-ion, but the net efficiency of the whole process can still be as high as 85 %. [76]

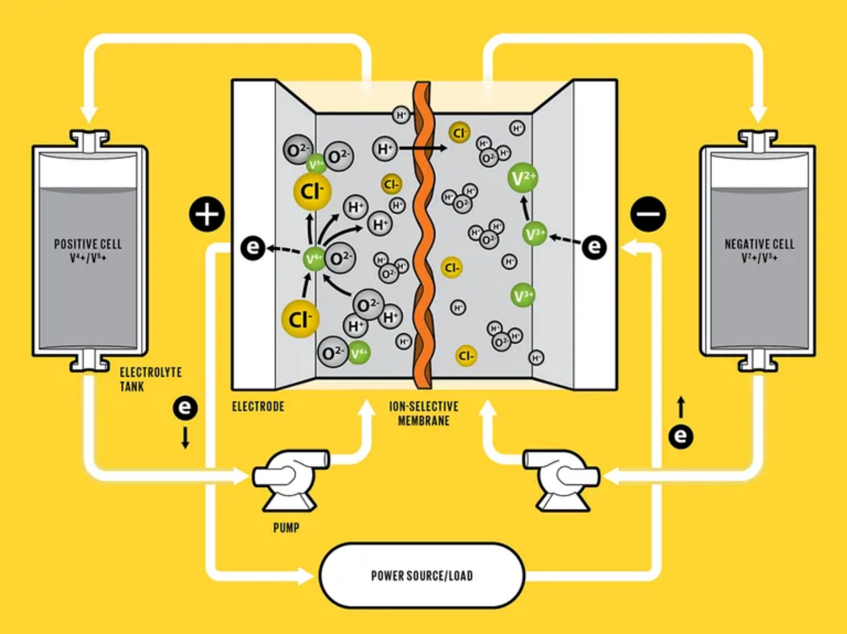


Figure 3.7: A Vanadium-flow battery with components [42]

One of the positive aspects of vanadium is that it does not degrade with time. If the system has no leaks, the lifetime of the battery will be longer than other technologies, with an expected durability of 20-30 years. Another advantage of flow batteries is that the capacity of the battery is easily scalable. With an increase in the tank sizes or the reactor, both the capacity and the rated power can be fitted to the application. They are also considered to be a safer option than lithium-ion. It is possible to discharge the battery down to 0 V_{DC}, so the maintenance and service of the stacks are safer with a much smaller chance of thermal runaway or fire. Vanadium is not as accessible as lithium and is known for being an expensive substance. Using other materials can affect performance, but the technology is also under heavy research. A hydrogen-bromine battery could be a huge possibility with specific energy ratings up to 530 Wh/kg. [25] [76]

One of the goals of this project is to evaluate the optimal storage option. The flow battery is a technology on the rise with a high ceiling, but at the moment the price can not compete with other battery technologies, mainly lithium-ion batteries. For storage at a small scale such as the old hospital, the flow battery could be suitable. This is because of the flexibility in capacity and power output, with mainly charging in the summer and discharging in the winter. A similar project has recently been done at Sluppen in Trondheim, where a 5 kW / 25 kWh vanadium flow battery was installed. This is worth monitoring, and useful data can be obtained from this experiment [79].

3.3.5 Hydrogen-storage

When approaching longer time frames, such as several months or seasons, hydrogen storage quickly becomes the preferable choice when there is a need to store excess energy. This is because of its many different areas of application. Hydrogen is the lightest and most powerful element and is very accessible. Hydrogen can be generated from electrolysis using excess renewable energy. Once generated, the hydrogen can be stored in different ways and then used to fuel the grid during the cold winter months.

There are two main ways to store hydrogen. Cryogenic hydrogen storage is a way to store hydrogen as a liquid, while compressed hydrogen storage is hydrogen stored under pressure. Cryogenic hydrogen needs to be stored at a cryogenic temperature of -253 °C and therefore requires special insulated cryogenic tanks. The main advantage of storing hydrogen as a liquid is its high energy density, which allows it to store more energy in a smaller volume. Cryogenic hydrogen has a density nearly twice that of compressed hydrogen and is also considered a safer storing option. Compressed hydrogen storage is the most established hydrogen storage method. During production, the hydrogen is typically compressed as a gas to a pressure between 200 and 500 bar. The compressed hydrogen then needs to be stored in high-pressure vessels, which could be one of four different types of vessels based on the specifications of the hydrogen in question. The biggest advantage of

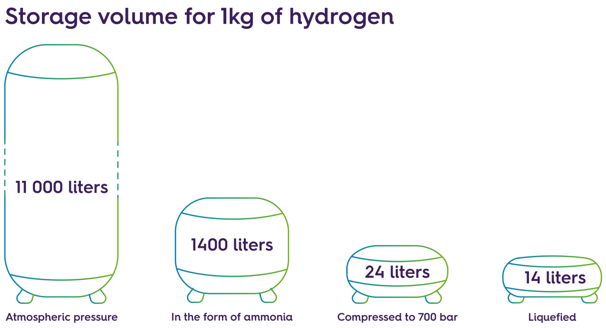


Figure 3.8: Required space to store Hydrogen [37]

storing hydrogen compressed is the opportunity of using it as fuel. Since most vehicles today have fuel cells that use compressed hydrogen to transform chemical energy into electrical energy, it means that it has the ability to refuel vehicles more rapidly. On the other hand, since hydrogen is stored as a gas, it requires larger pressurized tanks and takes up more space than liquid form.

Hydrogen has a low volumetric energy density of 0,09 $\frac{kg}{m^3}$ at atmospheric pressure, which requires a lot of space to store a small amount of product. The volumetric energy density increases with pressure. The theoretical volumetric density of liquid hydrogen is 70 g/L at -253 °C and atmospheric pressure, while it is 24 g/L for compressed hydrogen at 300 bar and room temperature. At 700 bar the energy density is 40 g/L. One of the disadvantages of using liquid hydrogen over compressed hydrogen is the energy requirement associated with the liquefaction process. As mentioned, a cryogenic temperature is required to keep the hydrogen in a liquid state. This intensive energy process of cooling consumes 25-40 % of the energy content of hydrogen, compared with just a 10 % energy loss for the compression of hydrogen. Due to several of these factors associated with cryogenic hydrogen storage, the application of it is limited to cases where high energy density is necessary. To keep the temperature low enough in the cryogenic tanks for a long period is costly, however, the compression of hydrogen is generally even more expensive [13, 50].

The required space to store hydrogen in different forms is shown in figure 3.8. One other storage possibility is using the Haber-Bosch method which is a chemical process to produce ammonia from nitrogen and hydrogen gases. Other possibilities such as storing hydrogen in metal hydrides and solid metals also have huge potential with new technology developing.

3.4 Hydrogen

Hydrogen is a high potential energy carrier, with zero climate gas emission, and will therefore play a vital role towards a greener future. It is possible to use hydrogen in the transport sector, in electricity production or to store excess energy. The latter is especially interesting because almost every new energy production plant will use renewable energy as its source, and will therefore not be able to control when energy is produced. If there are no ways to store the excess energy, the plants will end up wasting valuable energy. [28]

The process of using hydrogen as an energy carrier contains three main steps;

- Production
- Storage
- Usage

The production is done by obtaining hydrogen from sources that contain the material. The methods are defined through a color palette, shown in figure 3.9. After the gas is produced

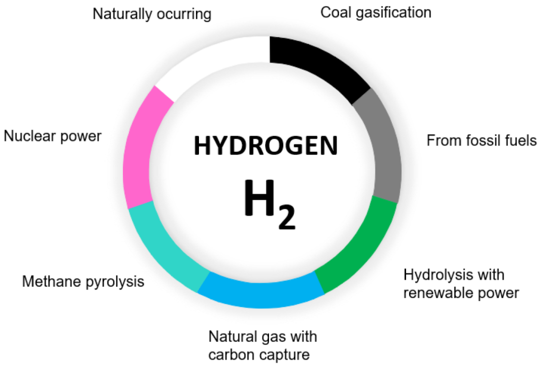


Figure 3.9: Hydrogen-production color palette [70]

the storage of the substance is the next step. This can be done in many ways with the possibility to use the liquid form with low temperature, storing it within solid-state materials or metal hydrides, or in gas form. [38]

Hydrogen has various applications after been produced and stored, including fuel cells, electricity generation, and industrial processes. When used in a fuel cell, hydrogen can be converted into electricity producing only water and heat as byproducts. In the transportation sector, hydrogen fuel cell vehicles are becoming more common due to their high energy efficiency and zero emissions. The storage possibilities best suited for this project are discussed in chapter 3.3.5. The main focus of this chapter will be the technologies and theory behind the production and usage of the substance. [38]

3.4.1 The colours of hydrogen

Almost 96 percent of the hydrogen production in 2022 is gray. Gray hydrogen is defined as hydrogen that is produced from coal, oil, or natural gas. It is a process called steam reforming where natural gas and water steam are brought together and hydrogen is the outcome. This method is the cheapest method of producing hydrogen. The challenge with gray hydrogen is that for every kg of hydrogen produced, almost 10 kg CO_2 is released into the atmosphere. Although it seems to work like a bridge to move on from fossil fuels, it is not the solution to the climate situation. [72]

Blue hydrogen uses the same process as gray hydrogen to produce hydrogen, but the big difference is that blue hydrogen captures the carbon emissions and stores them. Therefore, emissions do not reach the atmosphere and will not affect the environment negatively. This method has economic and logistical challenges but is still a more climate-friendly method.[78]

Green hydrogen is produced through electrolysis, a chemical process that uses electricity to split hydrogen from oxygen in water molecules. For the hydrogen to be called green, the electricity needs to come from a renewable energy source. Therefore, there will be no emissions from this process. The main challenge with green hydrogen is the high cost of electricity production from renewable energy.[78, 72]

3.4.2 Production

Green hydrogen production is the most relevant method for the Nothing Hill project since all the energy comes from renewable energy sources. It is a requirement that the electricity used in electrolysis is DC (direct current). There are several electrolysers for producing green hydrogen, and some of them are alkaline, polymer electrolyte membrane (PEM), solid oxide, and a relatively new technology, anion exchange membrane (AEM), electrolyser. The overall reaction is equal for all of the methods and is presented as equation 3.16.[36, 17]

$$H_2O(l) + \Delta Hr \Rightarrow H_2(g) + \frac{1}{2}O_2(g) \tag{3.16}$$

The ΔHr is the total heat of the reaction and can be found by equation 3.17.

$$\Delta Hr = \Delta G + T \cdot \Delta Sr \tag{3.17}$$

From this one can find the relationship between the reversible voltage and thermodynamic values, which is described in equation 3.18.

$$V^0_{rev} = \frac{\Delta Gr}{z \cdot F} = 1.229V \tag{3.18}$$

However, when splitting water, some entropy is generated. To find the minimum required voltage for the electrolysis, Gibbs free energy is changed to enthalpy as in equation 3.18, and a new equation 3.19 is obtained.

$$V_{TN} = \frac{\Delta H}{nF} = \frac{\Delta G}{nF} + \frac{T\Delta S}{nF} = 1.48 \tag{3.19}$$

Here V_{TN} is the thermoneutral voltage. This equation can be used in an ideal world, but that is not the reality. In the real world, there are irreversible losses, and in electrolysis, there are three main losses which are electrode losses, ohmic losses, and mass transport losses. Figure 3.10 shows how these losses affect the overall cell performance. [36]

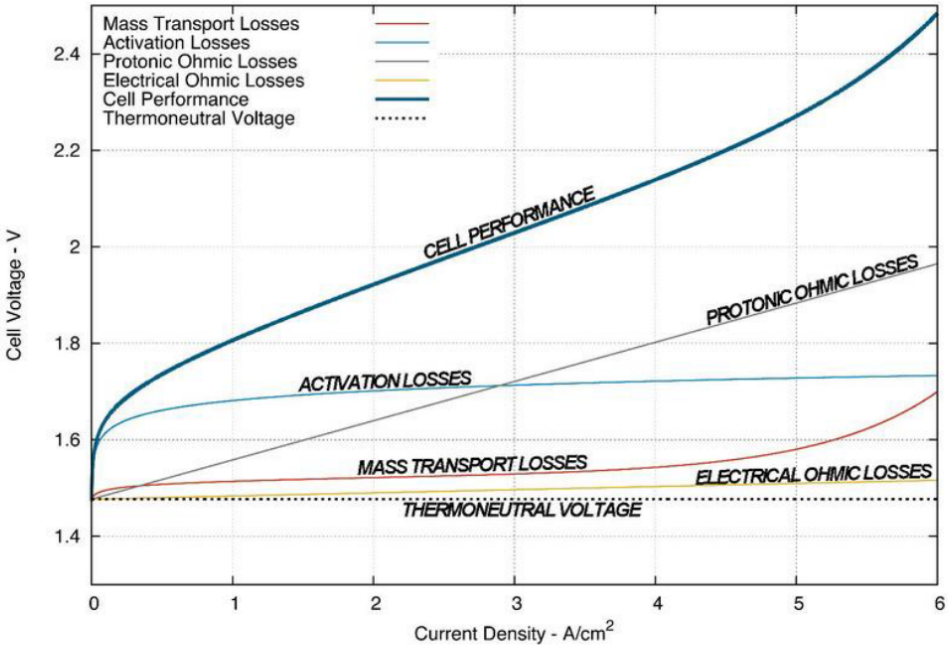


Figure 3.10: Types of losses in electrolysis of water [17]

Hydrogen has a Higher Heating Value (HHV) of 39,4 kWh/kg, which is the energy content for 1 kg of Hydrogen when the energy in the water produced is recovered. In comparison to other fuels like diesel and gasoline, which have a value of 12.67 and 12.69 kWh/kg respectively, this is high. However, to make a fair comparison, the entire process must be taken into consideration. The efficiency of the three main processes - production, storage, and usage - presents a significant obstacle to the widespread adoption of hydrogen. Inefficient processes lead to substantial energy losses, rendering them to not be sufficient to sustain operations. To calculate the efficiency of an electrolyser one would need the electric energy consumption for the electrolyser, but also the energy consumption for the other components such as pumps and gas separators is required. The efficiency can then be found by equation 3.20 [38]

$$\eta = \frac{m_{H_2} \cdot LHV(H_2)}{E_{Consumed}} \tag{3.20}$$

The next sections will dive into the different electrolysers, how they work, and the positive and negative sides of each.

3.4.3 Alkaline

Alkaline electrolysis is one of the oldest methods but is a relatively easy method to produce hydrogen. It was first introduced in 1789 by Troostwijk and Diemann. The hydrogen production starts at the cathode where two molecules of alkaline solution are reduced to one molecule of hydrogen (H_2) and the process produces two hydroxyl ions (OH^-). [46]

Figure 3.11 shows a simplified sketch of how the process works. The alkaline solution is often KOH or NaOH, where KOH is produce K^+ cations and OH^- anions. The concentration is usually between 20-40 %. The NaOH solution produce Na^+ cations and the same anions as a KOH solution. The KOH solution is often preferred as this has a higher ionic conductivity and the NaOH solution attracts CO_2 from the air easier than KOH, which further reduces the ionic conductivity. [46]

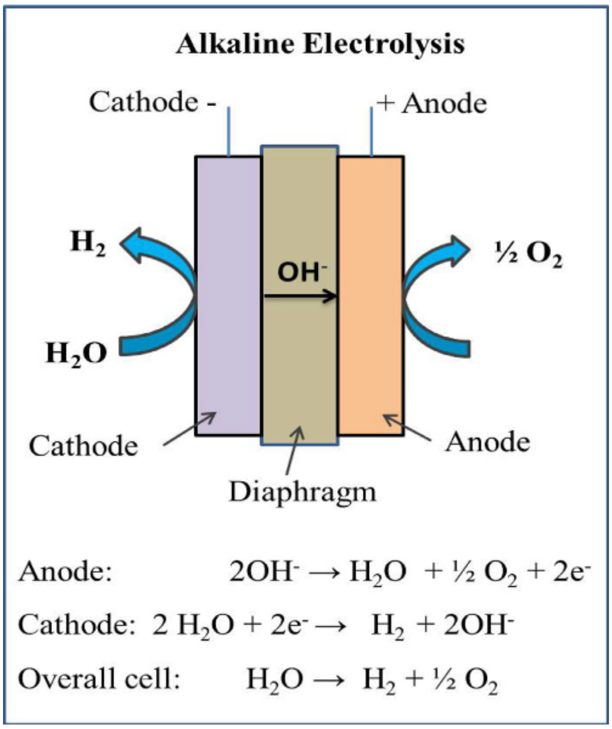


Figure 3.11: Alkaline electrolysis[36]

The OH^- on the cathode side is attracted to the anode because of the electric field. Between the cathode and anode, there is a separator or diaphragm that ensures that only OH^- is transported through. If electrons get through it would lead to a short-circuit, and if H_2 and O_2 have contact it would immediately return to H_2O.[46]

Most industrial electrolysers have an efficiency of about 65% and can produce hydrogen with a purity of 99.5% or higher. The efficiency could be higher if there were no additional components, but there are losses in the converter. The water purifier, gas dryer, and pumps use electricity which is included in the efficiency calculations. In addition to hydrogen, the process produces oxygen with a purity of up to 99.7%. This would either be sold or just be released into the atmosphere.[46]

The alkaline electrolyser can drop from nominal power with 15%, but the efficiency also drops. The nominal power is defined by the current density, and below nominal power gas can begin to slip between the separator. Therefore, the alkaline electrolysers are essentially steady-state units, and due to large current variations the amount of gas produced will vary. It can create temporary electrical insulation when the gas production changes, which leads to instability and inefficiency in the system. This technology is therefore not the best suited for renewable energy sources such as solar and wind, where the production of energy varies. In order to make this efficient, there is a need for a battery between solar and wind energy production and the electrolyser. [46]

3.4.4 PEM

The idea of PEM was first introduced back in the 1950s by Grubb and in 1966 General Electric was established. This method came to life to overcome the drawbacks of alkaline electrolysis. PEM works by splitting water at the anode and allowing the protons (H^+) to go through the membrane. Figure 3.12 shows how this works. The membrane is a solid polysulfonated membrane that is often made by Nafion or fumapem and has advantages such as high proton conductivity (0.1±0.02 S cm^{-}1), low gas permeability, and low thickness (20-300 µm) allowing high-pressure operations.[36]

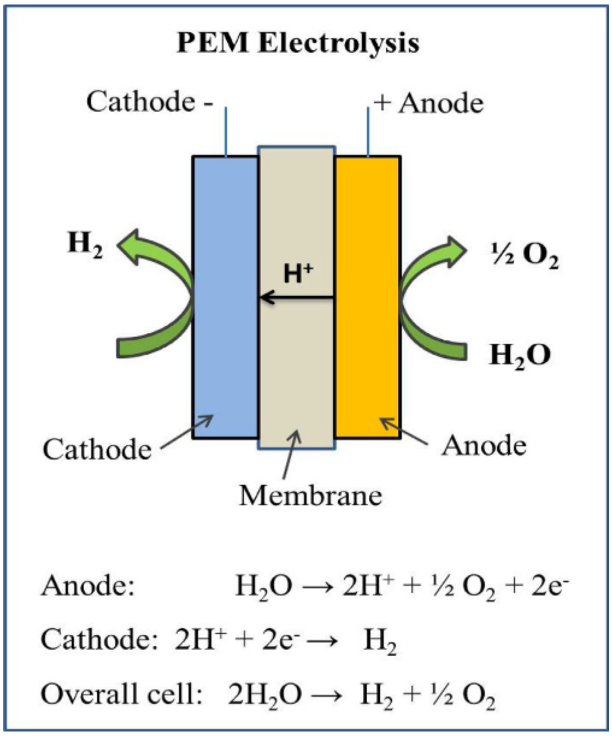


Figure 3.12: PEM electrolysis [36]

PEM operates at low temperatures, between 20-80 °C, and has a high efficiency of around 80%. Some PEM cells have reached an efficiency of 93%. The largest disadvantage today is the material costs since the cell uses noble metals such as platinum, iridium, and palladium. The main parts of a PEM electrolyser are the gas diffusion layer (current collectors), separator plates, and membrane electrode assemblies (MEAs). MEAs make up for 24% of the total cost and consist of ionomer solution, membrane, and the anode and cathode electrocatalysts. There are several ways to assemble MEAs, but the most common is the catalysts coated on the membrane method (CCM). Here is electrocatalyst slurry directly coated on the membrane, followed by a hot press with a temperature around 120°Cand 60 kg cm^{-}2 of pressure. The role of the electrocatalysts is to increase the charge transfer kinetics so the activation energy of the water electrolysis is decreased. The slurry is prepared with an ionomer, which increases the proton transport between the electrodes and the membrane. This decreases the ohmic losses and therefore increases the efficiency. The ionomer also works as a binder, which stabilizes the structure of the catalyst and adds durability to the electrodes. But the ionomer reduces the electric conductivity because it is electron resistant, so it is critical to optimize the ionomer content when preparing the slurry.[36]

The separator plates and the current collectors represent 48% of the overall cost, and it comes down to the material. The separator plates are made of titanium, stainless steel, and graphite and in addition to being expensive, there are also other drawbacks. The titanium gives great strength and thermal abilities, and also low permeability and resistivity, but on the anode side, the titanium corrodes. This decreases the performance, and to overcome this problem there have been studies to protect the titanium with different alloys or coating. But these solutions increase the costs of the cell.

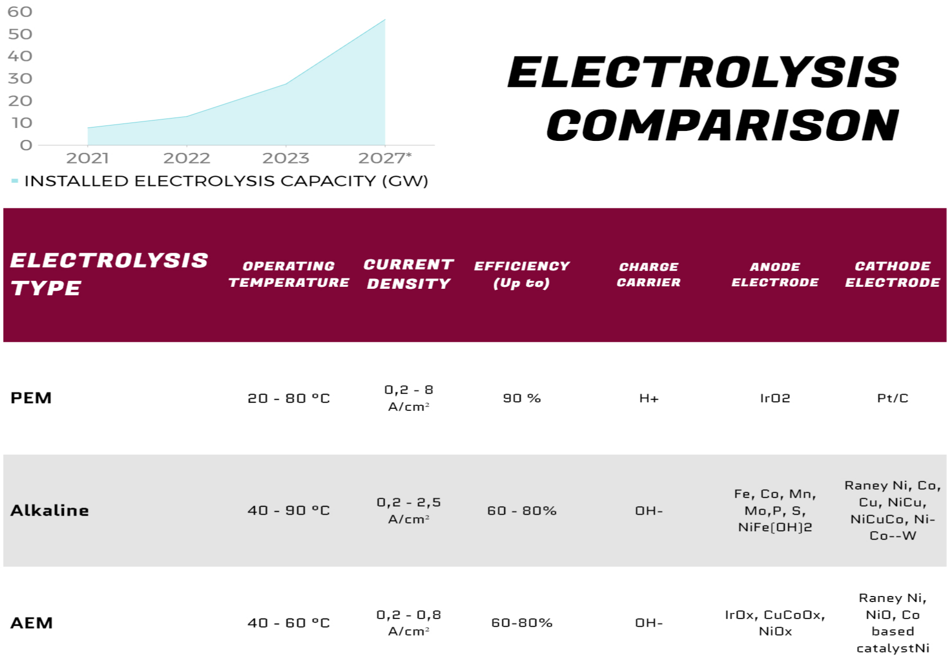
3.4.5 AEM

Anion exchange membrane electrolysis is a new promising technology under development. The method combines the best parts of alkaline and PEM technology to overcome the different challenges these methods have. The AEM cell is built similarly to the PEM, with a membrane between the anode and cathode, but the charge carrier is the same as alkaline (OH^-1). One of the biggest benefits of AEM is that it can avoid platinum group metals (PGM) as electrocatalysts, which reduces overall cost. The AEM is an immature technology and has some challenges to overcome before it is available on the commercial market. Even though it does not need PGM as electrocatalysts, the challenge is to find optimized chemical composition and stability for the new catalyst. The new catalyst has its drawbacks in comparison to the PGM, where the new will have more catalyst loading on the MEA and large Ohmic losses. This is due to the PGM-free catalyst having lower mass-specific activity.[74, 55]

Another challenge with AEM is the effect carbonation has on cell performance. Normally, the cathode does use pure O_2 or CO_2 to avoid carbonation, but the CO_2 in the ambient air can react with OH^-. This will make HCO_3^- and CO_3^{-2}. It is not beneficial to use CO_2 for the AEM, for this reduces the membrane resistance and electrode resistance, and will in the end negatively affect the performance.

3.4.6 Characteristics

Figure 3.13 presents the most important information about these methods. The methods are some of the most used technologies as of 2023, but within this field, the development in efficiency, materials used, and prices are expected to be a huge focus in the next period. Other technologies, such as the capillary fed-alkaline method, are introducing themselves to the market, but these have not been tested out in big-scale production yet [32]. This can affect both the efficiency, the materials used, and the prices, so the considered methods are the most suitable for our project.

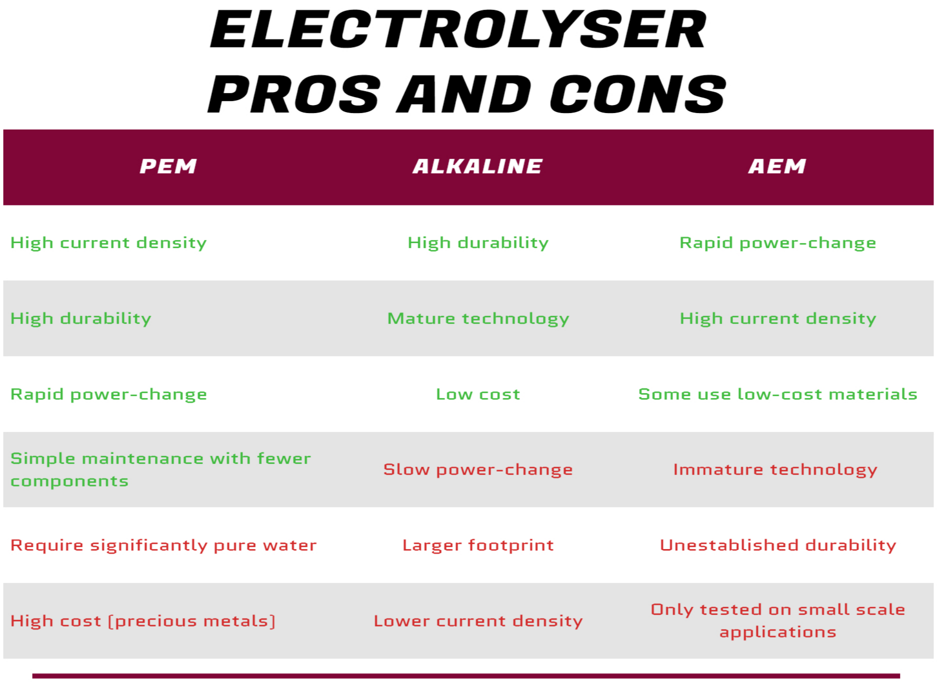


ELECTROLYSIS COMPARISON

ELECTROLYSIS TYPE	OPERATING TEMPERATURE	CURRENT DENSITY	EFFICIENCY (Up to)	CHARGE CARRIER	ANODE ELECTRODE	CATHODE ELECTRODE
PEM	20 - 80 °C	0,2 - 8 A/cm^2	90 %	H+	IrO2	Pt/C
Alkaline	40 - 90 °C	0,2 - 2,5 A/cm^2	60 - 80%	OH-	Fe, Co, Mn, Mo,P, S, NiFe(OH)2	Raney Ni, Co, Cu, NiCu, NiCuCo, Ni-Co--W
AEM	40 - 60 °C	0,2 - 0,8 A/cm^2	60-80%	OH-	IrOx, CuCoOx, NiOx	Raney Ni, NiO, Co based catalystNi

Figure 3.13: Electrolysis comparison [74, 46, 36]

Figure 3.14 displays the key characteristics of each method, with green indicating advantages and red highlighting challenges


ELECTROLYSER PROS AND CONS

PEM	ALKALINE	AEM
High current density	High durability	Rapid power-change
High durability	Mature technology	High current density
Rapid power-change	Low cost	Some use low-cost materials
Simple maintenance with fewer components	Slow power-change	Immature technology
Require significantly pure water	Larger footprint	Unestablished durability
High cost (precious metals)	Lower current density	Only tested on small scale applications

Figure 3.14: Electrolyser technology, pros and cons [74, 46, 36]

3.4.7 Usage

After pure hydrogen is produced and stored, the uses and applications for the product are many. Today, most of the element's usage is in industrial processes. About 55 % of global consumption is allocated to ammonia production, which is the main ingredient in fertilizer, while 20 % is used for petroleum refining. The remaining 20 % is used for various other purposes such as different kinds of fuel cells and methanol production. Using hydrogen as fuel in the transport sector has been a focus point for a long time, but as of 2022, there are only two models of Fuel Cell Electric Vehicles (FCEVs or HFCVs) available on the European market. The reason for the slow development is mainly the financial challenges. The cost of producing green hydrogen and using it as fuel makes the entire process too expensive to compete with fossil fuels and electric vehicles. Additionally, the refueling infrastructure is not as developed as either of the other options, with some citing safety concerns due to the risk of explosions. Despite these challenges, fuel cells are highly regarded because they only produce water and heat as byproducts. Hydrogen has an energy content three times higher than petrol, and the affection of cold weather doesn't have the same negative impact the hydrogen cars compared to EVs, making the distances possible to drive without having to refuel significantly longer. These factors suggest that efforts to establish hydrogen as a stable and profitable resource are likely to increase drastically when moving towards a greener planet. For this report, the fuel cell is a highly relevant factor in the energy storage process. For the energy stored through the electrolysis process on high production days to be converted back into electricity, the fuel cell is a main part, and the different technologies need to be presented to find the best possible solution. [40]

3.4.8 Fuel cell

A fuel cell is defined by FuelCell Energy as: *A system that converts chemical energy from hydrogen-rich fuels into electrical power and usable high-quality heat in an electrochemical process that is virtually absent of pollutants* [20]. Fuel cells can be used to power a wide range of applications, from small portable devices to large buildings and even vehicles, including cars, buses, and trains.

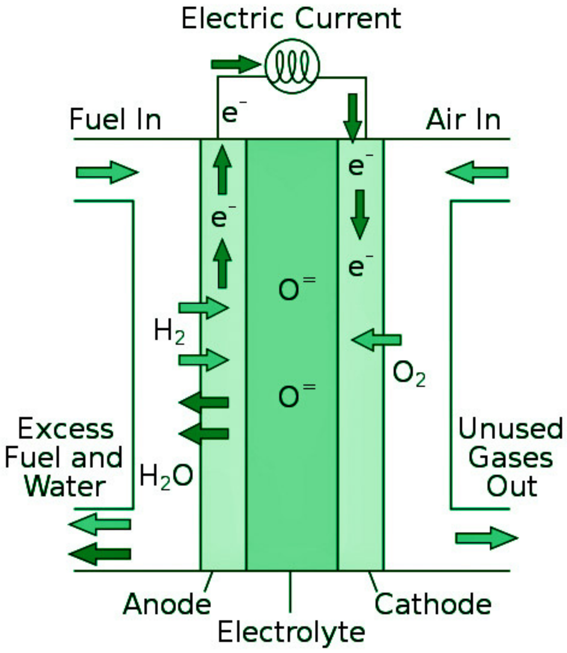
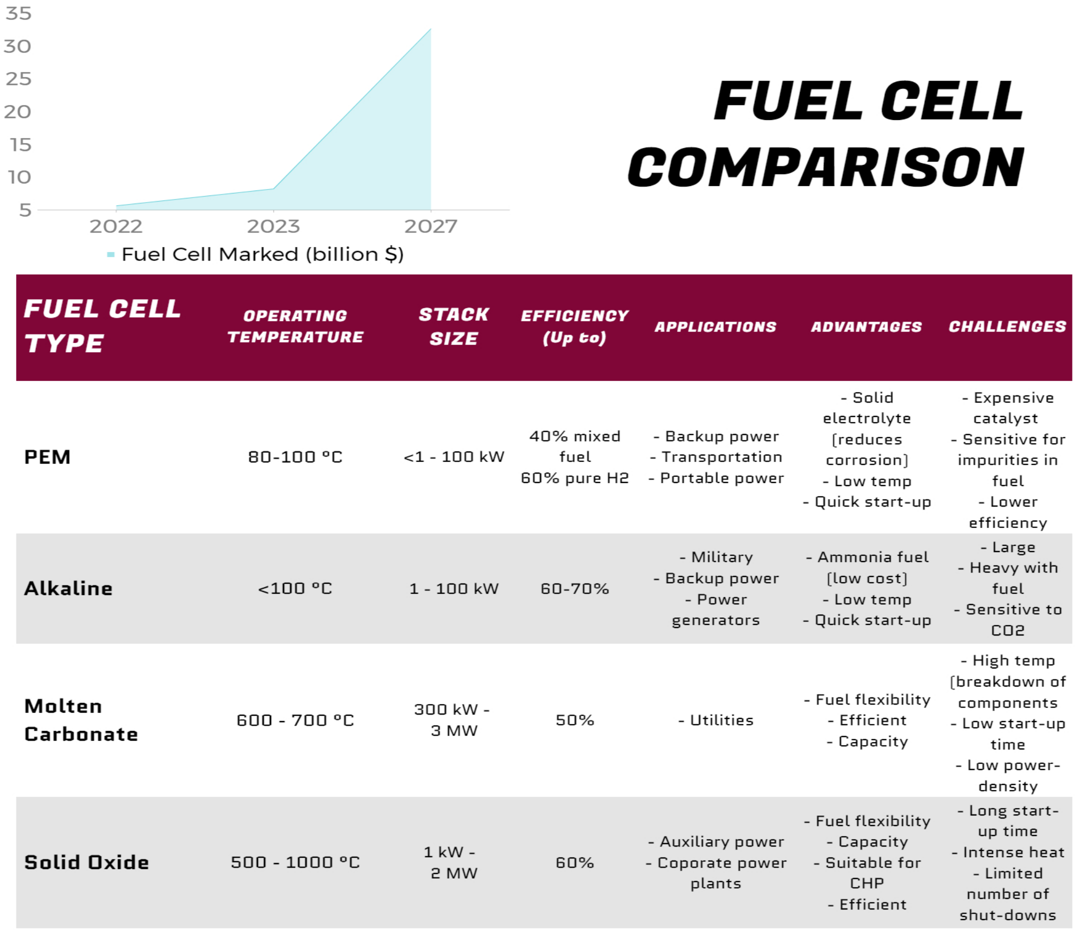


Figure 3.15: Fuel cell [27]

The technical aspects of a fuel cell are similar to a battery and contain an anode, cathode, and electrolyte layers. The main difference is that in a fuel cell, the reactants are continuously supplied to the system, while in a battery it is contained within the battery package. In a hydrogen fuel cell,l the reactions are the same as in the electrolysis discussed in 3.4.2, only the other way around. Hydrogen-rich fuel, optimally pure hydrogen, is fed into the system and reacts electrochemically with oxygen to generate electricity. The electrochemical reaction will be shown in equation 3.21, and the technical aspect in figure 3.15 where ΔHr will indicate how much excess heat that is produced from this reaction.

$$H_2(g) + \frac{1}{2}O_2(g) \Rightarrow H_2O(l) + \Delta Hr \tag{3.21}$$

The composition of the electrolyte is the main factor that distinguishes the various types of fuel cells. The types are mainly the same as for the electrolysis process, with Alkali, PEM, Molten-carbonate, and solid oxide being the main types as of 2023. The electrolyte used in the different types is the same as shown in figure 3.13. As the electrolysers, each fuel cell type possesses its own set of advantages and disadvantages, and the main characteristics are shown in figure 3.16. [4]



FUEL CELL TYPE	OPERATING TEMPERATURE	STACK SIZE	EFFICIENCY (Up to)	APPLICATIONS	ADVANTAGES	CHALLENGES
PEM	80-100 °C	<1 - 100 kW	40% mixed fuel 60% pure H2	- Backup power - Transportation - Portable power	- Solid electrolyte [reduces corrosion] - Low temp - Quick start-up	- Expensive catalyst - Sensitive for impurities in fuel - Lower efficiency
Alkaline	<100 °C	1 - 100 kW	60-70%	- Military - Backup power - Power generators	- Ammonia fuel [low cost] - Low temp - Quick start-up	- Large - Heavy with fuel - Sensitive to CO2
Molten Carbonate	600 - 700 °C	300 kW - 3 MW	50%	- Utilities	- Fuel flexibility - Efficient - Capacity	- High temp [breakdown of components - Low start-up time - Low power-density
Solid Oxide	500 - 1000 °C	1 kW - 2 MW	60%	- Auxiliary power - Coporate power plants	- Fuel flexibility - Capacity - Suitable for CHP - Efficient	- Long start-up time - Intense heat - Limited number of shut-downs

Figure 3.16: Fuel cell comparison [12]

4 Method and results

This section will give a more specific insight into the project. Based on the theory presented in section 3, it will highlight the methods used as well as the key findings. Additionally, the section provides the results obtained in terms of production and storage possibilities.

4.1 Excursion and practical data

As a part of the project, the group was invited by the High North Development group on a trip to Kirkenes. The purpose of this trip was to get a better insight and understanding of the project as a whole and explore the area.

Figure 4.1: The visit to Kirkenes provided valuable insights, shown by the old oil boilers and the roof for the PV panels

One important part of the project was to calculate the solar energy potential. To maximize the energy production the placing of the solar panels is vital, as debated in chapter 3.1. Therefore, observing the building made the task of picking out the ideal placement much easier. It became evident that certain locations were more favorable than others, as it became apparent that specific areas of the building created notable shadows when the sun was low. This parameter was difficult to estimate before the visit as there was no concrete detailed overview of the building. As a part of the work, three test PV panels will be set up after mutual agreement on the technical details. The test panels were meant to provide irradiation data that will be used in calculations later on in the project when the whole complete 10 000 m^2 PV system will be installed. These test panels will provide valuable data which later could be assessed and used to make adjustments to the placing and tilting of the panels.

Additionally, it would be insightful to set up a weather station to get more accurate measures of parameters such as wind speed and temperature. The weather station needs to be placed on the tip of the building to ensure that it had a natural location with as few potential disturbances as possible. The data of average wind speed for the location of the building will then become more accurate for future measurement.

The trip turned out to be a useful and instructive learning experience. It greatly helped us understand more of the project. In addition, it was a social and connecting experience. The group got the chance to meet a selection of people working on the project and got a better insight and understanding of the size and progress so far.

4.2 Solar production in the Nothing Hill project

The main energy source in this project will be the solar energy produced by PV panels covering a total area of 10 000 m^2. The primary location for these panels will be the rooftop of the main building. The specification sheet for the solar panels is attached in appendix A, and some of the data used for the calculations are based on this sheet.

The solar panels used in the project are of the brand GCL M8/72GDF. These are bifacial panels and are therefore able to utilize reflected sunlight from the snow. This will increase energy production, as discussed earlier. The specifications of the module are important when it comes to the energy output. At standard conditions of 1000 W/m^2 and 25°C, the rated power of each panel is 475 W, indicating a high power output in comparison to similar brands. The factors mentioned earlier, such as irradiation, shading, tilt angle, and temperature, will primarily impact the energy generation of PV panels. For optimal results, these uncertainties need to be accounted for when it comes to the placement of the panels.

4.2.1 Location of the PV panels

The main building had huge potential for placement of panels on the roof, as could be seen in the overview pictures in figure 4.2. With a total area of nearly 8000 m^2 available space, this is where most of the panels will be placed. However, the excursion to the location showed that the roof structure was found to be quite complex. Some height differences caused shading at different originally optimal places, and other obstacles that made the original plan change.

Figure 4.2: The available roof space for the solar panels

The solar panels need to face south for optimal energy output. This is not possible when the location of the panels is done practically for all panels because of the construction of the building. Some of the panels will have to be placed on walls and in slightly other directions to be able to fit all the panels into this system. The project is an owner of several other neighboring buildings to the hospital, thus the panels can be placed on these roofs as well. The number of panels needed with the optimal tilt will still be quite high, but it will not be possible to cover the whole area of 10 000 m^2. This could cause the practical data to be a bit uncertain, but it will not affect the results significantly.

4.2.2 Explanation of the chosen tilt angles

The discussion of whether to have a fixed angle or a panel that could track the sun is important. When it comes to theoretical maximum energy output, the optimal tilt angle is discussed in section 3.1.5. It is necessary to test if it is worth the investment because the solar tracking system is quite expensive. Another challenge with continuously changing the angles of the panels is the high snow rates at this specific location during a large part of the year. With snow depths at the roof that potentially could reach one meter, the panels must be lifted quite high from the roof. Since the energy production in Kirkenes is almost zero from November through January, this will only be a potential problem during February, March, and April, however, this need to be taken into account.

With the sun being low in Kirkenes at most parts of the year, the shading factor also needed to be evaluated. Different ”backtracking” programs can be used to make the modules follow the sun and tilt the angle optimally so the panels do not interrupt each other's production.

For this project, the ideal setup would consist of tracked panels on the roof. The location is 69 °North, and the amount of energy produced is more than 35 % more than if all the panels were fixed angle. There will be a fixed angle for the panels placed on the walls, and the pitched roof will be facing south for the most optimal production. This will affect the practical data, but the snow reflection and the Albedo effect make accurate numbers almost impossible to calculate. The calculations done in this project are therefore based on the ideal angle and have been temperature-corrugated, however, snow reflections and the non-ideal placement are not accounted for. Despite this, the calculations give an estimate of how much energy theoretically can be produced from the 5000 panels in this project.

4.2.3 Solar results

All the different angles of every hour in the year have been calculated with equation 3.2, 3.3 and 3.4. The process of the calculations is shown in appendix C. However, all of the angles cannot be shown, so the tilt angles for noon on the 15. of every month are shown in table 4.1.

Table 4.1: Tilt angles

Month	Tilt angle 12:00 15.xx.xxxx
January	91.02
February	83.06
March	72.57
April	60.32
May	50.94
June	46.42
July	48.22
August	55.95
September	67.52
October	79.37
November	88.91
December	93.07

The cell temperature was calculated with equation 3.1, and the different cell temperatures for each month are presented in table 4.2.

Table 4.2: Cell temperature

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp ℃	-5	-4.69	-1.6	4.09	7.81	12.04	15.55	14.45	11.29	3.44	-1.96	-4

The different efficiencies were then calculated from these cell temperatures, followed by a calculation to find the produced energy from one solar panel. Appendix D shows how this was done. The energy produced with temperature correction is shown in table 4.3

The total energy produced from one panel was 393 kWh. To achieve enough energy, it is necessary to use 5000 of these panels. The whole production will then be 1965 MWh.

Table 4.3: Energy produced with temperature coefficient included

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
kWh	0	6.46	31.27	62.58	76.04	73.91	64.07	44.79	23.92	9.19	0.94	0
Total	**1965 MWh**											

The calculated energy production without temperature correction is shown in table 4.4. The total is 315kWh, which is significantly lower than the calculations that include the temperature correction. The total here becomes 1575 MWh and is 390 MWh less than the result with temperature correction. Figure 4.3 visualizes the difference between the two results.

Table 4.4: Energy produced without temperature coefficient

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
kWh	0	4.38	21.94	46.91	59.66	61.23	55.67	38.33	19.62	6.83	0.66	0
Total	**1575 MWh**											

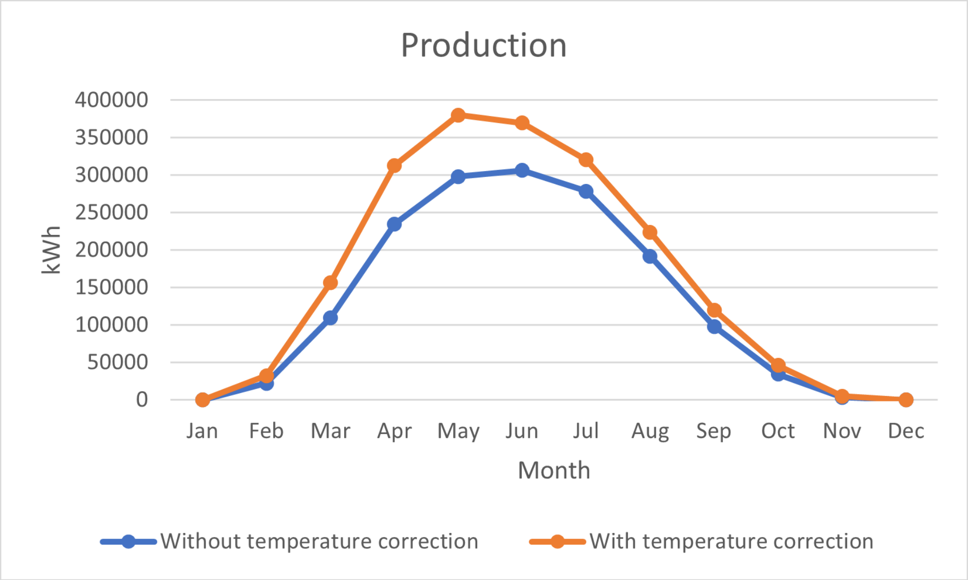


Figure 4.3: Comparison of solar energy production with and without temperature correction

4.2.4 Sources of error

The sources of error for the solar calculations include the solar radiation data source, the PV model, as well as how the calculations are done. The calculations are based on the location, and as known Kirkenes is a remote location, far north. So in addition to the regular sources, the location also brings uncertainty to the data because there is little information and research done about how solar energy works this far north.

The solar radiation data in this project is obtained from the database Meteonorm 8.1, which is the most frequently used database in solar energy modeling. Meteonorm combines historical data with modeled data and gives out estimated radiation based on this. Newer databases are available on the internet, but the extra cost of these is not worth the more realistic data. Meteonorm is widely used, and a trustworthy site, so using the radiation data from this site does not impact the uncertainty factor negatively.

The efficiency of the PV model is a crucial factor in the calculations, as it significantly influences the results. Therefore, the PV model is a part of the uncertainty analysis as well as the calculations. The efficiency is affected by many elements, but some are temperature and irradiance. The PV module company has released information about how temperature affects efficiency, and this is taken into account in the calculations. The efficiency goes down for lower irradiance, but it does not say how much, and since it is a remote location the irradiance data is only monthly and not hourly. The calculation method in this project is based on the textbook ”Solar energy engineering” by Soteris A. Kalogirou, which is the same textbook used in the solar energy class at NTNU. This does not include factors such as shading, Albedo effect, or tilt losses. Another method for calculating the energy output would be to use a simulation program like PVsyst. The problem with PVsyst for this project was that the PV module is not in the database. Also, the program just gives out a result and makes it hard to analyze which parameters were included in the calculations. But it is a popular program, and the company claims that the results are supposed to be very accurate, so it is a highly relevant alternative.

In conclusion, the results are not 100% certain and can lead to errors later when dimensioning the hydrogen production. The main goal for the solar calculations was to calculate the theoretical maximum yield from the PV panels, and this is meant to be optimal, without shading and with the optimal tilt for every hour. This will not be the case in this project, because the cost for the optimal solution will be too high. In almost every realistic project the ratio between cost and yield is extremely important, while in these calculations maximizing the yield was the only task. A program like PVsyst would have provided more realistic results, however as mentioned, the program did not have the specific module which is used in this project. Since Nothing Hill is in its start-up phase, it would be wise to get the module added to the program. Then it would be possible to run a realistic simulation including shading and a fixed tilt.

4.3 Wind production in the Nothing Hill project

As a part of the Nothing Hill project, there will be a total of 20 wind turbines producing renewable green energy. The chosen turbine is a vertical-axis wind turbine (VAWT) of the brand RW500 from the company IceWind. The wind turbine specification sheet is attached in attachment B. As explained in chapter 3.2, topography and climate will affect energy production. Therefore, it is important that the turbines can cope with a variety of conditions. The model in use in the project is a robust prototype that has been tested in harsh conditions in Iceland and is proven to tolerate the challenging climate north of the arctic circle. These vertical-axis wind turbines are built to be mounted in several various areas, designed to tackle wind speeds up to 217 km/h. The turbines will consistently deliver power, even in the harshest conditions such as snow, ice, and sand storms. One of the biggest advantages of RW turbines is that they require little or no maintenance for over 20 years, in addition to being easy to install and operate.

With the plan to install 20 of these turbines, the total energy output will contribute to the grid system, supplementing the energy generated by solar production.

4.3.1 Location of the wind turbines

When the project shall choose the location of the wind turbines, there are some important factors that need to be evaluated. The site should have sufficient wind speed and consistency to be able to generate the desired amount of energy. To get the most accurate data, it is also important to ensure that the turbines are placed in such a way that they have free access to all wind directions because these are unpredictable in nature. Placing wind turbines too close to walls, roofs, or other structures can reduce their energy production. In addition, the topography can impact the wind flow and turbulence and may affect the efficiency and lifespan of the turbines. It is also important to ensure access to the necessary infrastructure to be able to connect the turbine to the grid and perform maintenance if needed.

4.3.2 Wind results

It was important to calculate how much energy one of these turbines could produce to be able to calculate the total energy production from wind. By using equation 3.9, it was possible to calculate the total energy output from the wind turbines. The total energy output one of these

RW500 wind turbines is able to produce in one year is given in table 4.5, and sums up to 716,6 kWh. For a total of 20 turbines, it is possible to produce 14 332 kWh. For the system, the monthly average production is an important factor to calculate. It is essential to know how much energy can be used, or eventually stored during the summer months.

Table 4.5: Energy production from wind turbines in Kirkenes and the power output

Wind speed (m/s)	**Power output (W)**	Hours	**Energy output (kWh)**
0 - 2,5	0	1837	0
2,5 - 3,5	20	1322	26,4
3,5 - 4,5	40	1302	52,1
4,5 - 5,5	60	1109	66,5
5,5 - 6,5	80	951	76,1
6,5 - 7,5	100	757	75,7
7,5 - 8,5	150	561	84,2
8,5 - 9,5	230	428	98,4
9,5 - 10,5	350	248	86,8
10,5 - 11,5	515	136	70,1
11,5 - 12,5	660	63	41,6
12,5 - 13,5	785	25	19,6
>13,5	910	21	19,1
TOTAL			**716,6**
TOTAL from 20 turbines			**14 332**

Based on the average wind speed in Kirkenes for each month, the calculated total energy production for one turbine is shown in table 4.6. The expected energy production is quite similar for each month, with a slightly higher output during the winter season. The projected energy production for each month is calculated as a percentage of the total energy production based on the average wind speed for each of the months respectively for the most accurate data.

Table 4.6: Monthly energy production based on the average wind speed

	Average wind speed (m/s)	**Monthly energy production (kWh)**
January	5,0	65,4
February	5,0	65,4
March	5,3	69,3
April	4,5	58,8
May	4,4	57,5
June	4,4	57,5
July	3,9	51,0
August	3,6	47,1
September	4,2	57,9
October	4,7	61,5
November	4,8	62,8
December	5,0	65,4
TOTAL		**716,6**

Figure 4.4 shows the yearly production from all 20 turbines, divided into monthly averages.

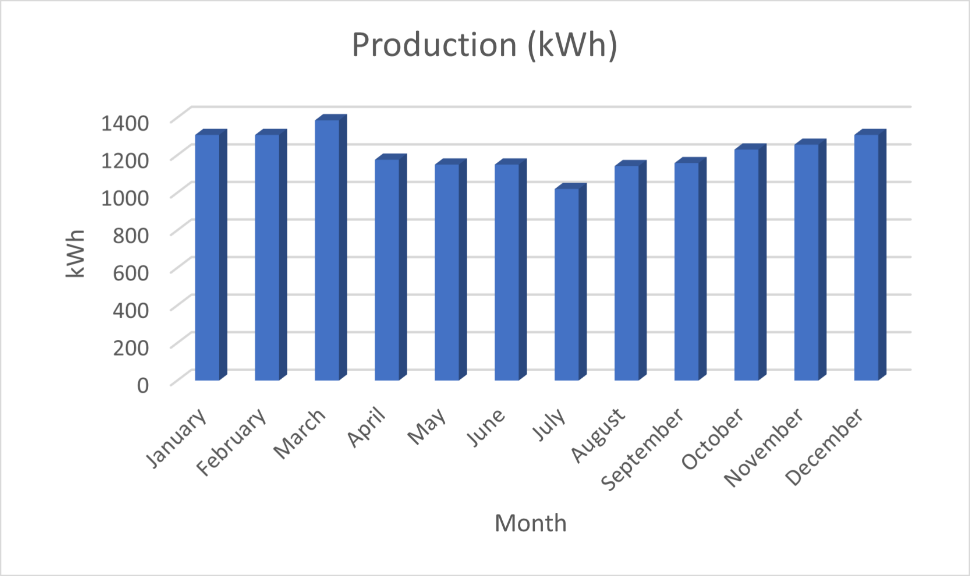


Figure 4.4: Yearly energy production from the wind turbines

4.3.3 Sources of error

The results show that the energy produced by wind is a small percentage of the total energy production in comparison to the energy produced by the sun. This indicates that the sources of error in the wind calculation do not play a big part in the total energy production calculations. However, some potential sources of error are important to consider. The most apparent factor is the uncertainty surrounding the wind data resource, much like solar energy. This uncertainty has to do with where the data is obtained from, and the limitation in the measurement process at the meteorological towers. As wind speed and energy production do not show a linear relationship, the sensitivity factor considering wind variations becomes important as well as the sensor accuracy. The energy production from the wind turbines will vary from time to time due to variations in wind speeds. Because of these variations, short-term wind measurements of 1-3 years will not provide solid enough data in comparison to a longer-term estimate.

There will also be an uncertainty associated with the power curve of the wind turbine. As known, the power curve indicates the power output for each different wind speed and is one of the main parameters when estimating energy production. The terrain characteristics of the location often result in wind flow patterns that differ from those for which the wind turbines' characteristic curve was designed. As a result, the power curve output may vary slightly with factors such as turbulence and topography playing a substantial role in these variations. These factors can impact the power curve of the wind turbines and make them unreliable. The power curves are therefore often given with an uncertainty between 4-6 % if tests are made, and 8-10 % in the case of no testing. [53]

Like for any technology, unforeseen technical failures or operational disturbances can lead to a reduction in the power output as well. It is important to pay attention to the environmental conditions that the turbines are exposed to. Kirkenes is a place that is more exposed to harsh conditions than many other areas. It is therefore important to take this into consideration in this project. Humidity and condensation are significant risk factors that can affect energy production. Studies have demonstrated that dry air has a higher density than humid air, which can impact the power output of wind turbines. Due to its lower density, humid air can lead to lower power production. The advantage of using the RW500 turbines from IceWind is that they are better able to cope with these challenges overall compared to other turbines. It also makes electrical failures less likely to happen.

4.4 Total energy production

The total energy produced from solar and wind was calculated to be 1.980.242 kWh/year, and the monthly values are presented in figure 4.5.

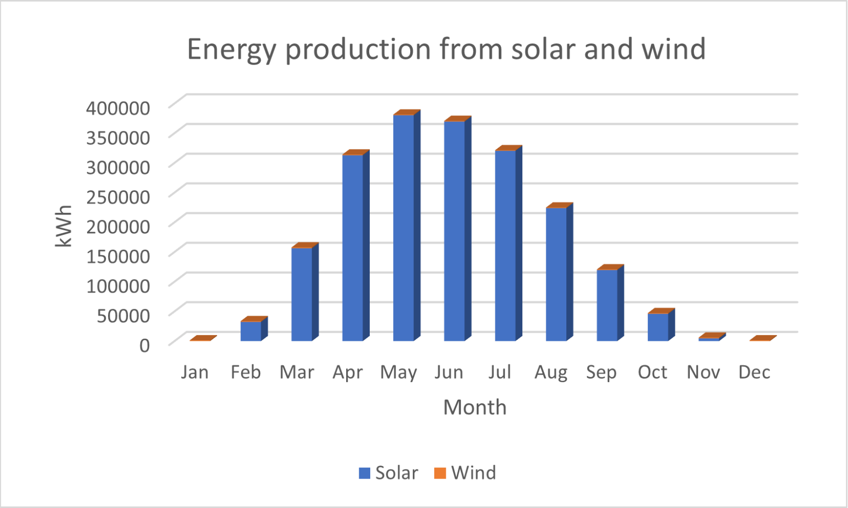


Figure 4.5: Energy produced from solar and wind per month

4.5 Energy consumption

The quantification of energy consumption within the building is crucial to be able to determine the amount of energy that has to be produced for achieving a status as an energy-plus house. The energy budget for the building from 2021 was given to us by our supervisor. However, these values were collected in a period when the project barely had started. These numbers are used for further investigation of the consumption of the building because they give an indication of the different demands from day to day and the variety from summer to winter. The monthly values used in the cases are scaled from the consumption from 2021 because here daily values were reported.

To ensure that cases were built on reliable information, it was appropriate to examine a scenario in which the building meets the energy requirements of TEK-17, a standard set for new buildings in 2016. Here the energy consumption for universities and similar buildings is set to be below 125 $kWh/m^2/year$ [16]. With an overall area of 22 000 m^2 in the building, the energy consumption in the building has to be below 2,75 TWh/year. This is a difficult comparison to do since the materials used in the building have not been accounted for. The emission from the materials are unavailable, but the materials used for renovating the building should be carbon-neutral.

Another example of a comparison that was evaluated is comparing the Nothing Hill project with

Powerhouse Brattørkaia in Trondheim. This is a self-served energy building from 2019 which is defined as the northernmost powerhouse in the world with production mainly from PV panels placed on the roof and walls of the building. The building has an area of 18 200 m^2 with an own annual energy production of 485 000 kWh through 3000 m^2 of solar cells. This is enough to keep the building self-served just by solar energy. The building has an extremely low energy consumption, with many incorporated methods which reduce and reuses the energy spent within different sectors through these innovative innovations. Examples are that the energy spent on lighting in the building has been reduced by 50% by using natural light, the energy spent on heat is reused in different forms, the usage of sea-water for heating and cooling is utilized and the concrete used in the building process are made with very low carbon emissions. [65]

To give a comparison to the status of today, it is worth having a look at similar buildings in NVE's report from 2016 [49]. This will give a good indication of how the building is going to behave, even though the building will be renovated. Table 4.7 is used as a comparison tool when it comes to calculating the future consumption and use of energy.

Table 4.7: Energy consumption in similar buildings

	Nothing Hill building in 2021	To fulfill TEK-17	Energy plus building	Brattørkaia	Average university in Norway (2016)
$kWh/m^2/year$	176	125	90	33,5	260
Size (m^2)	22 000	22 000	22 000	13 500	Average 14 000
Renewable production methods	-	Solar, wind, geothermal	Solar, wind, geothermal, modern innovation systems	Solar, modern innovation systems	-
Energy production from renewables	0	1 980 242 kWh/year	1 980 242 kWh/year	485 000 kWh/year	-
Total consumption (kWh/year)	3 867 667	2 750 000	1 980 242 (without efficiency for storage)	478 288	5 720 000 (if 22 000 m^2)

4.6 Storage

As shown in the previous sections, the different storage options perform differently in terms of the various parameters. In this project, a large amount of energy needs to be stored for a longer period. Therefore, the energy density was one of the most important things to be considered. The specific energy is the amount of energy stored in a system in comparison to its mass, and this must therefore be taken into account when choosing how to store the produced energy. The comparison of the different methods is displayed in figure 4.6.

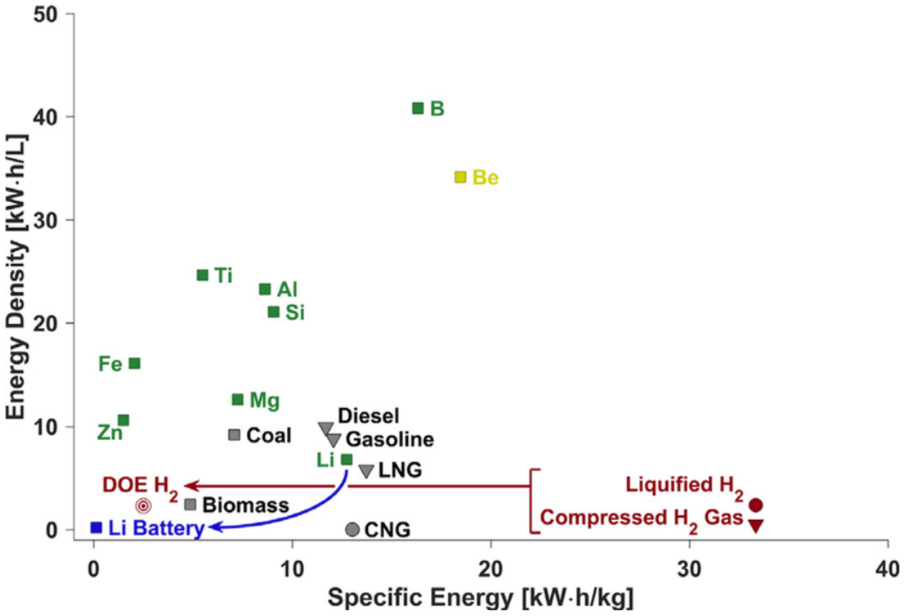


Figure 4.6: Chart of selected energy densities [23]

As shown in figure 4.6, the specific energy density of hydrogen is superior to the rest of the alternatives including natural gas, diesel, and gasoline. Lithium-ion batteries, which are ranked among the top batteries, are only a small percentage in specific energy compared to hydrogen. Liquid hydrogen has the highest volumetric energy density out of the hydrogen options, which was expected as gas molecules take up more space.

A comparison of costs among the various alternatives revealed that hydrogen is a highly viable option. Batteries are generally cheaper and more cost-effective to store energy at small scales or for a short duration of time. However, when approaching longer time frames, such as weeks, months, or seasons, storing the energy as hydrogen will be multiple times more cost-effective than batteries. Most of the large-scale batteries of today are very expensive, with most of them only able to store energy for a short period. Although it is clear that the total efficiency of hydrogen storage is way below lithium-ion batteries, studies have shown that hydrogen provides a similar energy return when it comes to storing excess energy from wind turbines and solar panels [61].

4.7 Hydrogen in the project

Before hydrogen is stored, it has to be produced with the optimal method for this project. Some of the possible methods are discussed in chapter 3.4. For the electrolyser, the three types presented are all possible to use for production. However, the High North Development group has received an offer from a company for an electrolyser, a storage tank, a compressor, a dispenser, and a refueling station. The main specifics of the offer include:

- 1000 kW Alkaline electrolyser
- Potential production of 200 $Nm^3/hour$

- 99,99 % pure hydrogen at 2 MPa
- Compressed to 20 MPa and 45 MPa to increase the specific energy density
- Stored in a 450 bar tank

The original idea for the use of hydrogen, in this project, was a refueling station, however, this part of the process is not decided. To be able to implement this project, the village depends on utilizing the hydrogen stored to meet the energy demands during periods of higher consumption than production

The need for a technology that doesn't require constant supervision and follow-up is a key factor for the project, as discussed in chapter 4.6. It is also important with high efficiency. Due to the limited number of professionals specializing in the field of hydrogen in the Kirkenes area, the hydrogen process must be self-sufficient and not rely on too much external expertise or support. In terms of efficiency, the PEM-electrolyser has been found to outperform other types and has demonstrated superior performance metrics with high current density and rapid response times. When using renewable energy, there is a possibility for rapid change in current, and the alkaline method is proving to not be sufficient for these changes. During the operation of an alkaline-electrolyser, the generation of hydrogen (H_2) and oxygen (O_2) bubbles is an inherent aspect of the process. However, when the production is halted and restarted, these bubbles can accumulate and cause an increase in degradation of the components of the electrolyser. This can result in a decrease in power density and a reduction in the overall efficiency of the system. For this project, this is not sufficient, with the changes between production and electricity generation happening daily and quite rapidly. Considering all of these factors, the PEM-electrolyser will be the technology chosen for the further investigation of the different cases.

The selection of appropriate fuel cell technology is also an important factor for this project. The energy stored as hydrogen must be transformed back into electricity in the most suitable way. The fuel cell's operational temperature is a crucial consideration that affects its performance and efficiency. In addition, the technology used in fuel cells must be capable of swiftly and smoothly transitioning between producing electricity or not, similar to that of electrolysers discussed. From figure 3.16 these points indicate that the alkaline and the PEM technologies are the most suitable. The main differences between the PEM and the alkaline are the cost, and the alkaline is significantly more affordable. When using fuel cells in cooperation with renewable sources alkaline is shown not to be as sufficient as PEM. This was the most suitable technology for this project. Table 4.8 provides a summary of the selected technologies for the project, along with their corresponding efficiencies.

Table 4.8: Chosen hydrogen technologies

	Chosen technology	**Efficiency**
Electrolyser	PEM	75%
Storage	Compressed	90%
Fuel cell	PEMFC	60%

In a hydrogen system, the mentioned efficiencies are important to be able to calculate the electricity used on low-production days. By using a PEM-electrolyser with an efficiency of 75% for hydrogen production, a quarter of the energy produced is lost. The hydrogen is then compressed and stored, and the efficiency in this step is around 90%. When hydrogen finally is used in the fuel cell, the efficiencies vary greatly, however, with new technologies the efficiency is around 60%. [52]

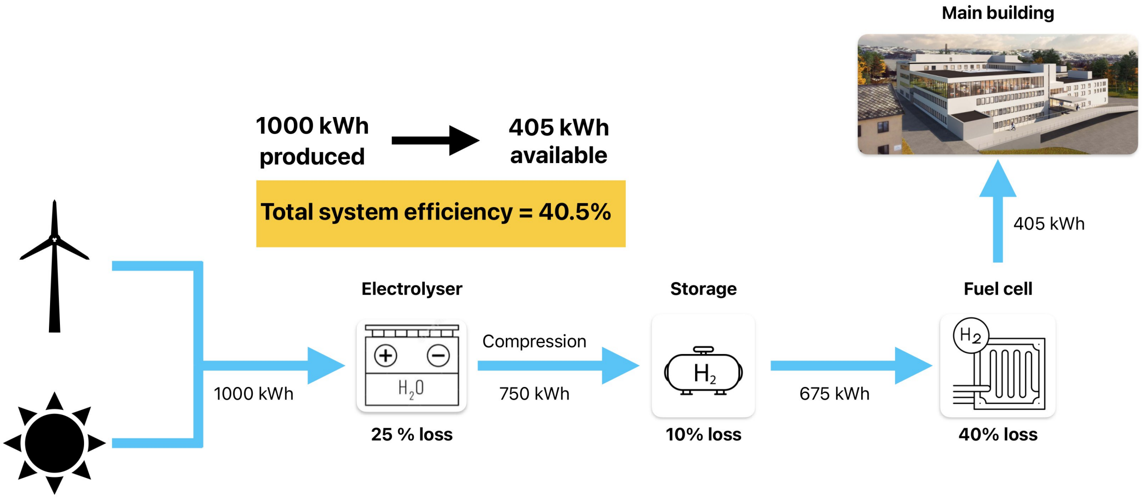


Figure 4.7: The quantity of energy generated that is available for reuse after the hydrogen process [52]

Figure 4.7 shows an estimate of the amount of energy generated during energy-positive days that can be utilized following a period of storage. Here 1000 kWh is used as a reference number. The relevant numbers for this project are discussed in the interplay section 5.

4.8 Carbon emissions

To analyze how renewable energy sources can reduce carbon emissions was a critical aspect of this project. This part is not included in the thesis, but a brief look at how much emission one can reduce will be discussed below.

To be able to classify this project as a carbon-neutral system an environmental calculation, such as a Life Cycle Analysis(LCA), must be done. In this calculation, all the materials used in the process are taken into consideration and put into an emission calculator. If the system only relies on renewable energy production methods, emissions during the usage period would be estimated as negative when looking at it carbon-credit-wise. However, for the system to meet the definition of carbon-negative, the lifespan of the system is typically evaluated over a 60-year period. This will therefore include the materials used in the building process. To indicate the potential emission reduction by integrating renewables into the project, a look at similar projects can serve as a useful benchmark.

In Australia, a project replaced its energy production from diesel generators with wind turbines and PV panels. The original installed capacity was rated at 9,1 MW. This was then replaced by

10 MW of installed power from PV arrays and 9 MW from wind turbines. With the inclusion of a 15 MW electrolyser, a 2500 kg storage tank of hydrogen, and a 4 MW fuel cell the system became fully reliant on renewable energy and hydrogen storage. The emissions from the system were reduced by 99,6%, making this an almost carbon-neutral system. The inclusion of fuel cells has also been tested in hospitals around the U.S., with a 400 kW model powering a 32 000 m^2 facility. This fueled 63% of the electricity consumption and reduced the carbon footprint by 652 metric tons each year. A hydrogen facility in Turkey was powered by floating PV panels, and able to fulfill 99.43% of electricity without a grid and backup generators. These examples demonstrate that the concept behind the project is feasible and has been successfully implemented on a large scale, despite the various challenges that need to be overcome. [31] [26]

If the system has a connection to the larger grid, the possibility to sell the excess energy produced on net-positive periods back to the grid can give carbon credits. This will make it possible to buy back energy from the grid when production is low for a long period, such as the winter season. Thus, the system will not only rely on the storage unit. This will make it possible to have a smaller storage facility. To be able to sell energy will have a great impact on the economic output of this project, and will be an important factor for the calculation of the costs. This will be discussed in chapter 4.9.

4.9 Financial comparison

To optimize the financial aspect of this project's energy system, it was necessary to conduct a brief financial comparison of the most suitable options. This involved an evaluation of the prices of PV panels, wind turbines, and the different storage units. The production of energy will be through solar and wind in each of the evaluated processes.

The international energy agency, IEA, says that alkaline electrolysers have a cost between 500-1400 USD/kW, while PEM costs between 1100-1800 USD/kW. The fuel cell cost between 600.000-800.000 USD with the same power used in the cases, so in the calculations the average, 700.000 USD, is used. The price of the electrolyser is compared to the proposition the High North Development group has received, with a compression unit and cables included in the price. The price for the different power capacities needed in the different systems was then calculated as shown in 4.9.[18, 1]

The cost of storing compressed hydrogen at 300 bar is around 700 USD/kg H_2. This is compared to the proposition and gives a good indication of how this unit will affect the price. The planned capacity is 438 kg for the two methods with electrolyser and fuel cell, with a little less when a battery is included in the package. A kilogram of hydrogen has an energy density of 33.6 kWh/kg, which means that 438 kg of hydrogen has 14716,8 kWh. On average, as the building is now, the energy consumption is 350 000 kWh/month. This means that the planned capacity is not enough to provide energy for the winter months. The capacity does still give an example for the financial estimations, since the building is going to be renovated, and the energy consumption will be drastically reduced. [24, 21]

The cost of one bi-facial PV panel (500W) is between 300-500 USD [2]. The nothing hill project is going to have 5000 panels, and have received an offer with a total cost for all panels to be approximately 750.000 euros. That means one PV panel costs around 160 USD, and installation of the PV panels is included in these costs which is a quite low price for this sector. With an exchange rate of one euro to be 11,36 NOK as of 2023, this results in an expense of approximately 8 000 000 NOK. The total cost of the wind turbines is set to be 2.207.960 NOK, with a unit price of 110.398 NOK.

The installation and maintenance costs for the hydrogen system have been estimated based on the proposal the firm has received. The proposed use case for the hydrogen was in a refueling station, which necessitated the installation of cables from the production site to the pump. However, if hydrogen can be produced, stored and reused in a more compact space, the associated costs could be reduced. Calculating the exact cost savings in this regard is challenging, so it represents the most uncertain part.

Table 4.9: Brief financial comparison of the different systems

	PEM-electrolyser and PEMFC	Alkaline-electrolyser and PEMFC	Lithium-ion battery (8 MWh)	Battolyser (Alkaline-electrolyser, 1,4 MWh Li-ion + PEMFC)
Wind turbines	2 200 000 NOK	2 200 000 NOK	2 200 000 NOK	2 200 000 NOK
PV-panels	8 500 000 NOK	8 500 000 NOK	8 500 000 NOK	8 500 000 NOK
Electrolyser	18 000 000 NOK	14 000 000 NOK	-	12 000 000 NOK
Storage-unit	4 000 000 NOK	4 000 000 NOK	14 000 000 NOK	3 000 000 + 2 800 000 NOK
Fuel cell	7 000 000 NOK	7 000 000 NOK	-	5 000 000 NOK
Installation and maintenance	1 200 000 NOK	1 600 000 NOK	100 000 NOK	1 600 000 NOK
TOTAL	40 900 000 NOK	37 300 000 NOK	24 800 000 NOK	35 100 000 NOK

Most of the new green projects will not be financially profitable. This is a huge problem for the development of such projects. Therefore the governments have begun to provide monetary support to help to make such projects possible. In Norway, there are two big state-owned associations, Enova and Innovation Norway that can give financial support to projects like the Nothing Hill. In 2023 Enova gave 1.12 billion NOK to different hydrogen projects [22]. Innovation Norway has given support to the Nothing Hill project for the start-up investigations. The Nothing hill project has applied for more funding now that the project has started to take form.

It is anticipated that the hydrogen sector will undergo substantial financial development in the coming decade, with a significant decrease in prices projected. As of 2022, the cost of 1 kg of grey hydrogen was rated at 1.50 USD/kg, whereas green hydrogen was priced at 5 USD/kg. To make green hydrogen a financially sustainable method, a substantial reduction in its production cost is required. It is projected that by 2030, the cost of green hydrogen will decrease by 80 % to reach 1 USD/kg, making it far more financially reliable. In 2018 the rated price for a PEM-electrolyser was as mentioned between 1100 - 1800 USD per kW installed capacity, but was expected to drop to 450 USD/kW within 2030. The fuel cell cost was expected to drop from 1300 USD/kW to 1000 USD/kW. These predictions are based on marked evaluations, which indicate a far more significant drop than what other renewable sources have gone through to reach a manageable price. [7] [59]

5 Interplay of the energy system

Figure 5.1 illustrates the configuration of the project's grid system and demonstrates how the various components interact and impact each other.

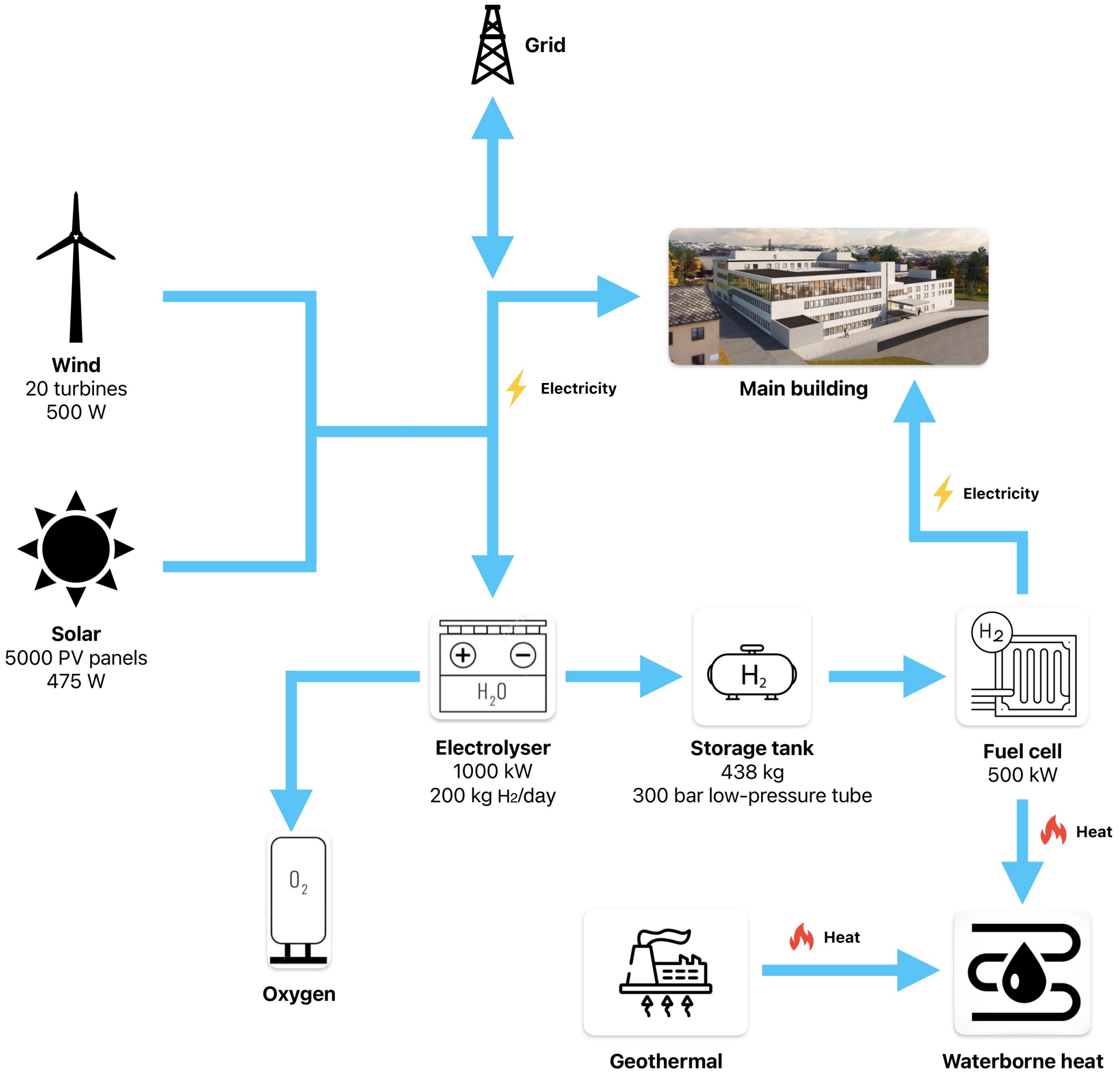


Figure 5.1: The interplay of the energy system

The system is using solar panels and wind turbines as the main energy sources. The produced DC can either be directly converted to AC to meet the electrical demands of the main building or utilized in the hydrogen conversion process by using an electrolyser. Since the electrolyser employs DC in the hydrogen production process it can be utilized without passing through an inverter. Oxygen is generated as a byproduct of the electrolysis process and can be taken advantage of by using it for other purposes such as medical applications or industrial processes. Once the hydrogen is produced in the electrolyser, it is stored in compressed storage tanks until required for use whenever the energy supply is in deficit. In the fuel cell, hydrogen reacts with oxygen to produce electricity. In addition to the electricity produced directly for the building, this process also releases a great amount of heat. Geothermal energy production will primarily produce heat. The heat from the geothermal energy production, and the excess heat from the fuel cell combined with excess heat from the data center will be used to heat the building and lower the electric heating demand.

Within a year there are a lot of different variables which influence the production, storage, and usage. However, there are also other small affecting factors, such as the number of people in the building at a certain time, but these are insignificant in comparison to the delivering energy source. This chapter will therefore focus on the weather aspect, by creating different scenarios. There are several scenarios of different weather, but to simplify, two scenarios are created for this project. Case A represents a day in the summer, while Case B deals with a typical winter day. Finally, there is set up a third case where calculations for the whole year are done, to indicate the year-round energy budget to make it easier when distributing and managing it throughout the year.

5.1 Assumptions

To perform calculations related to the interplay of the energy system, certain assumptions had to be established. These assumptions were necessary to simplify the analysis and provide a framework for the calculations. Without these, the complexity of the energy system would make it difficult to obtain accurate and useful results. For this project, the chosen assumptions include:

- The calculations are made for the main building, due to a lack of data for the surrounding buildings in the village
- The energy consumption will have a similar distribution throughout the year as in 2021
- The solar energy production is calculated based on tracked solar panels
- 100% of the heat demand will be covered by geothermal energy production
- The calculated total energy production of 1980 MWh/year from the solar and wind sources is correct
- 1 MW power for the electrolyser
- 500 kW power for the fuel cell
- The building has a peak power demand of 650 kW

The information on the energy consumption in the building is limited. The hospital will be renewed and parts of the building were in bad shape, which resulted in low energy quality. The goal for the renovated construction is to be an energy building of high quality and hopefully decrease the U-value from the old, poorly insulated parts of the building. At the same time, most parts of the fundamental structure will still be the same to avoid the whole building to be demolished. The energy consumption of the building discussed further in this report has been calculated by comparing it with other buildings of similar size and use. This approach provides a reliable estimation of energy usage based on industry standards and benchmarks. Since the building is to be used for different purposes the most comparable information will be within the university/office sector.

According to NVEs report from 2016, the energy consumption in universities is estimated to be 260 $kWh/m^2/year$ [49]. This is a reliable number since NVE gathered information from over 150 cities. The consumption in the different sectors of the building is shown in figure 5.2.

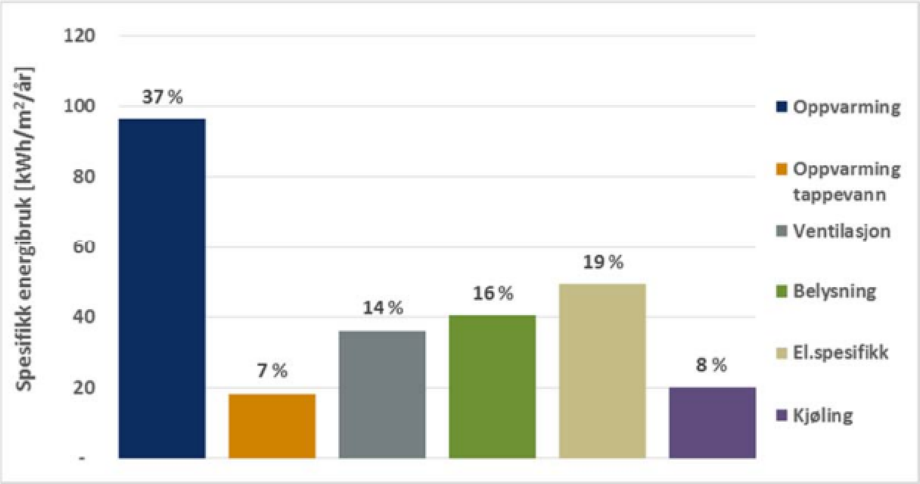


Figure 5.2: Consumption of energy within different sectors in a university building [49]

Heating and hot water accounted for 44% of the total energy consumption in these buildings, as shown in figure 5.2. The incorporation of geothermal heat will be a crucial element in the waterborne system for this project. It is assumed that this heat source will be sufficient to fulfill the heating requirements, which reduces the energy consumption in the building by almost 50%. This element will also be affected by the fuel cell, which produces heat in the process when electricity is produced from hydrogen. Further on, this means that the heating part of the building will be fully covered.

The theoretical energy produced by the PV modules and wind turbines is calculated to be 1.980.242 kWh/year. There is uncertainty associated with this result, but further on in the cases, this result is assumed to be correct. This is the only way to be able to find out how the different energy components will interplay in this system. Since our role in this project is to find the optimal energy solutions, and not think of the cost, the PEM electrolyser was chosen. The assumed power of the electrolyser is 1 MW, and to get the specific data about the electrolyser, an actual electrolyser from H-TEC systems is used as a reference. The module name is H-TEC PEM Electrolyser ME450. The fuel cell assumed in this project has a power of 500 kW and uses PEM technology. The peak power demand of the building is not known, but when compared with another building the peak should be around 650 kW. So the fuel cell does not cover this but helps to shave the demand from the grid. [49]

5.2 Case A - a sunny day

Case A is a day in June when the sun will provide a significant amount of energy through a 24-hour period. This will maximize solar energy production, and hydrogen production will be at its peak during this day. This way it is possible to find out how big the electrolyser must be to utilize all the excess energy. Although energy from wind is not at its peak this month, it only accounts for 0.73% of the overall production. Hence, it can be disregarded when selecting the day with the highest production.

The total energy production is higher in May. This is only because May is 31 days, while June is 30 days. The average daily production during May is 12301 kWh, while in June it is 12356 kWh. The difference is not large, but in June the building needs less energy due to the outside temperature being higher. In addition, there are fewer people in the building using electricity because of vacation. It is also more natural daylight, and not necessary to use all the lights. Normally the electricity for heating also is decreased in June. However, this will not influence this project because all the heating energy is covered by geothermal energy.

The energy consumed by the building on June 15. 2021 was 7820 kWh, and is shown hourly in figure 5.3. This data comes from a year when the building was almost empty, and there were no events or tenants. As the figure 5.3 shows there are no significant spikes in consumption, and usually there is a lot more consumption during the day.

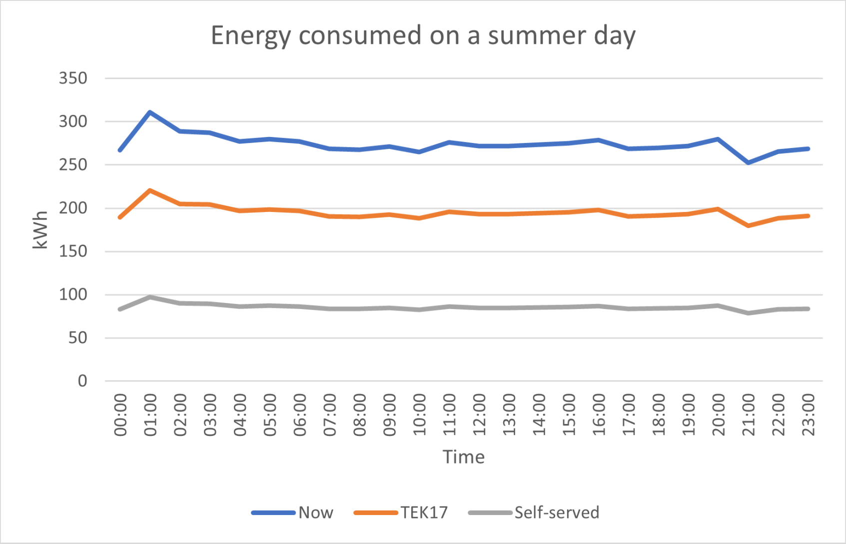


Figure 5.3: Energy consumed during a summer day

Figure 5.4 shows the production on a summer day, the consumption on a summer day in 2021, and what the consumption would be if the building achieved the TEK17 requirement. As the building stands, the energy surplus energy would be 4536 kWh, with TEK17 the surplus is 6804 kWh, and if the building is self-served the surplus is 10302.1 kWh. This energy is going to be stored as hydrogen, and one loses 25% in the electrolysis, and then 10% in the compression. The possible stored energy is 3061.8 kWh as the consumption is now, 4592.7 kWh at TEK17, and 6953.92 kWh when the building is self-served.

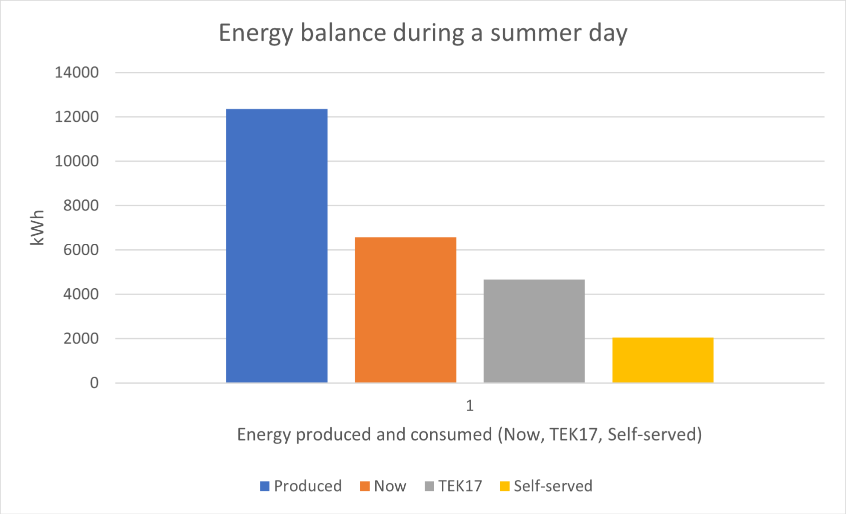


Figure 5.4: Energy balance during a summer day

5.3 Case B - a winter day

Case B will show an example on how production and consumption during a low-production day in the winter season could look like. The solar production will be equal to zero due to the polar nights, while the wind turbines will generate a small amount of electricity around 42,2 kWh. However, this is not enough to sustain the whole building throughout the day. Thus, the hydrogen stored must be used in the fuel cell to generate electricity. Figure 5.5 shows the energy produced and the energy consumed for the different scenarios.

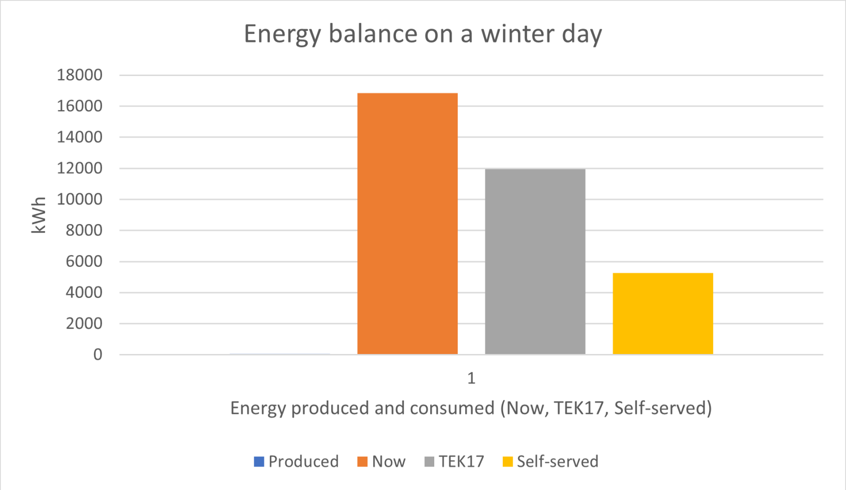


Figure 5.5: Energy balance during a winter day

To get all the energy, needed on a winter day, from hydrogen, the building would need to be self-sufficient. The other scenarios require help from the grid to have enough energy. The fuel cell has an efficiency of around 60%, which means to cover the demand of 5255 kWh when the building is self-served, around 8758 kWh, which is 260,7 kg of hydrogen, is required. The storage tank that the project had been offered had a capacity of 438 kg.

5.4 Case C - All year

Case C shows the overall energy budget, and how the project will operate throughout a year. The energy budget is very dependent on energy consumption, as mentioned in chapter 5.1. This was difficult to obtain in this project. Therefore Case C will have different energy budgets for different energy consumption. The cases will be based on the current energy consumption, the TEK17 standard, in addition to a system where the building is self-served.

Figure 5.6 show how the yearly energy budget will look with the consumption being the same as in 2021. During May, June, July, and August the production will be higher than the consumption, with a total surplus of 337 MWh during these months. For the remainder of the year, the system consumes a substantially greater amount of electricity than it generates, with a total shortfall of 1 887 424 kWh needed to achieve self-sufficiency.

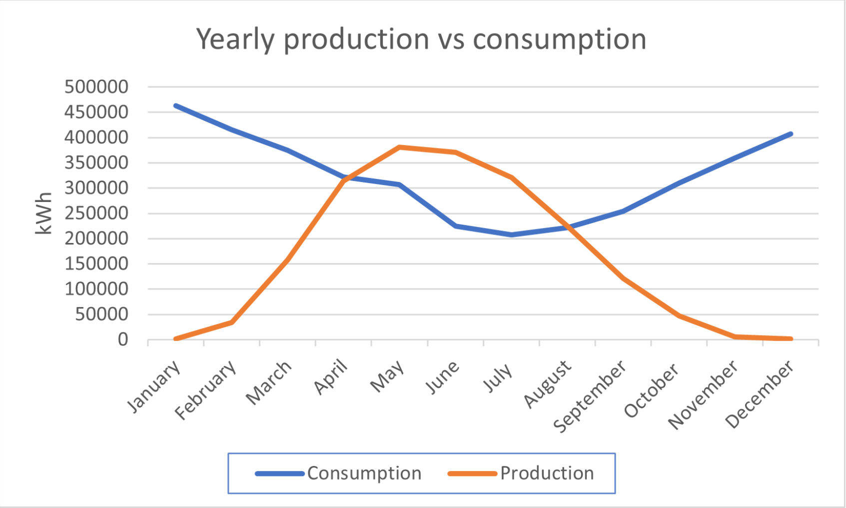


Figure 5.6: Yearly production vs consumption 2021

To fulfill the demands set in TEK17 the consumption of the building needs to be reduced by 28,9%. Figure 5.7 shows the monthly budget, and with this consumption, the excess electricity during the summer months is 700 MWh. There are still some reductions in consumption that need to be done, to make a sustainable energy system with a total deficit of 770 MWh.

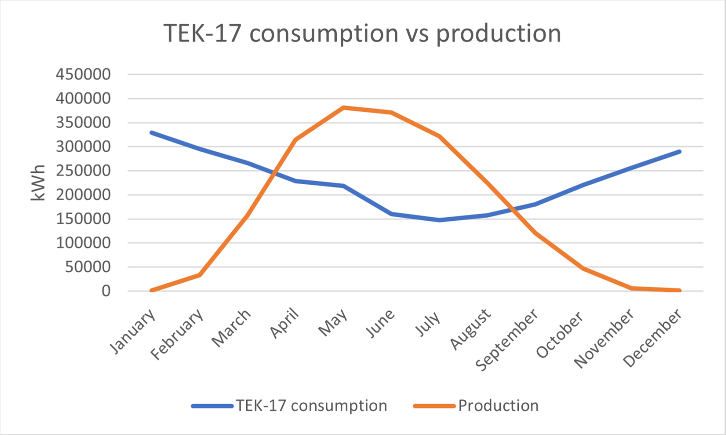


Figure 5.7: Yearly production vs TEK-17 consumption

For the building to be able to go under the definition of a energy plus house, the production must exceed the consumption on a yearly basis. For this to happen a drastic reduction in the energy consumption have to be done, because as mentioned the yearly deficit in electricity is 770 MWh even when the building fulfills the TEK17 standard. Figure 5.8 shows the monthly energy budget if the building is self-servant with energy.

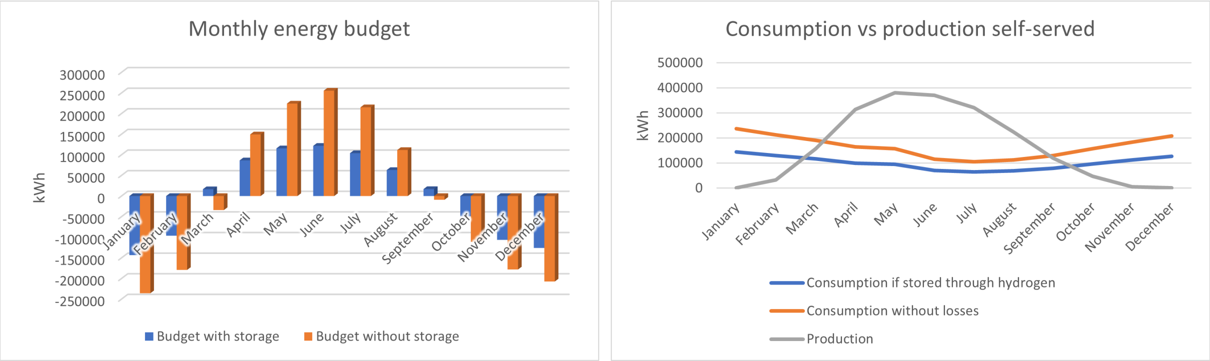


Figure 5.8: Energy budget for the building, storing excess with hydrogen vs selling back to grid

The budget, if the energy is going to be stored through a hydrogen storage process, is shown in blue. Here the efficiency for the excess energy produced to go through an electrolysis process, compression, storage, and then used in a fuel cell is taken into consideration as shown in figure 4.7. This requires the consumption in the building to be reduced by 68,8% from the numbers from 2021, to reach 54,84 kWh/m^2/year to be self-served with energy throughout the year. If the electricity produced on net-positive days is sold or stored with a minimal amount of losses, the consumption can be equal to the production to go under the definition of energy positive. This is shown in orange color and gives the building the possibility to use a significantly greater amount of energy throughout the year. With a production of 1980 MWh in the system, the consumption for the building must be below 90 kWh/m^2/year to be able to go under the definition of a powerhouse.

If the building is going to be self-served, which means it does not need to buy energy from the grid, all the electricity needed must come from hydrogen. The surplus energy is in total around 1.300.000,00 kWh and is 877.500 kWh in stored hydrogen. To store this at 350 bar, the size of the tank would have to be almost 1250 m^3, which is half the size of an Olympic swimming pool.

6 Discussion

Overall, there are many aspects in the Nothing Hill project that must be evaluated. The project is huge, with several different minor programs that will be included. A system where an old building, such as the old hospital, is renewed and then self-served with energy, are not very common. This gives few comparison tools. The evaluated points can vary, and the depth of information can be almost infinite. Within the thesis for this report, the main parts are as mentioned the production possible with the given production methods and how this can be utilized on a yearly basis.

6.1 Energy production

The electric energy produced in the Nothing Hill project will be generated from PV panels and small wind turbines. It is important to remember that the project has a geothermal energy system as well, which will cover most of the building's heat demand.

The difference in the production of energy between summer and winter is large, as seen in figure 4.5. The total energy production sums up to be 1985 MWh. The total energy production from the 5000 PV panels is calculated to be 1965 MWh, while the total energy produced from the 20 wind turbines is estimated to be 14 332 kWh. Wind production will therefore make up only 0,73 % of the total energy production. During the winter, wind production will account for all the self-produced energy, with almost no solar production. Since wind production makes up such a small part of the total energy production, it will not be produced much energy during the winter at all, and the system will then rely on the excess energy stored. Due to the midnight sun, it is possible to produce solar energy for 24 hours of the day during the summer months. This is the key to producing as much energy as possible. It is essential to store all the excess solar energy produced in this period so that it can be utilized during the winter months when energy production is low.

As mentioned, the energy production from the wind turbines plays a small role. However, the financial part of the turbines is the significant factor. The total cost of the whole renewable energy system in Nothing Hill is estimated to be 10.7 million NOK. The turbines contribute to 20% of this cost. Considering that wind turbines contribute with only 0.73% of the total energy production, it raises the question of whether the cost of having wind turbines is justified. The wind production part could therefore be seen more as an experiment than as a significant energy-producing source for the project. This provides a chance to observe how the turbines function and to analyze the performance and results. This will give information about the possible potential, which can be used to decide if it is worth to progress with wind turbines at a larger scale in the future.

To get an indication of whether the solar energy production results from this project are realistic or not, it is possible to compare them with similar projects like the Powerhouse Brattørkaia. Since the PV panels in the Nothing Hill project are estimated to be able to produce 1965 MWh each year, while Powerhouse Brattørkaia has a total annual production of 485 MWh, the solar results obtained in this project seem realistic. In the Nothing Hill project, 5000 panels cover an area of 10 000 m^2 compared to a total area of 3000 m^2 in the Powerhouse. The theoretical production, therefore, makes sense with the panels having almost the same power output to area ratio. This shows that optimizing of the tilt angle is important, and confirms that the calculated angles for the project are least close to optimal. There are also several other factors that distinguish the two projects. One of these is the fact that Kirkenes has a slightly lower average temperature than Trondheim. It is worth noticing that the results show it will be produced 390 MWh more energy from the panels when the temperature coefficient is accounted for in the calculations. This is because solar cells work with better efficiency at colder temperatures, which explains why it is possible to have solar production as far north as in Kirkenes. The temperature coefficient of the solar cells is -0.35%/°C. Therefore, the colder climate in the Arctic north in comparison to warmer places significantly enhances the total solar energy production. In addition, the albedo effect which also includes snow reflections highlights the benefits of implementing solar cells as far north as possible. Additionally, the PV modules used for the Nothing Hill project are new modern panels of the highest quality. It is important to have high-efficiency panels in buildings where the goal is to be labeled as plus-houses. Higher-quality panels degrade more slowly and generate more power in a given space than older panels which could result in significantly higher power output.

6.2 Energy storage

Kirkenes is a remote area with a small population, and energy shortage is seldom an issue. The storage of all the energy produced is considered the main possibility. The Nothing Hill project evaluates several storage solutions. Some of them are discussed in this report, such as thermal energy storage, different types of batteries, and hydrogen. As shown in chapter 4.6, the energy density in terms of volume and weight varies among different types of storage units. The intended use of the storage must be considered when selecting the appropriate storage method.

With the results presented in chapter 4.6, the most suitable method for this project and thesis is storing energy through hydrogen. When evaluating whether to store the hydrogen compressed or as a liquid, the purpose of the storage must be taken into account in the assessment. As mentioned in chapter 3.3.5, the process of liquefying hydrogen requires cooling it to a cryogenic temperature. This requires energy, but once the hydrogen is in a liquid state, it can be stored more densely than compressed hydrogen. This means that less storage space is required for liquid hydrogen than for compressed hydrogen. As a result, this will reduce the storage costs. In this project, the hydrogen needs to be stored for a long period of time, since it is produced in the summer and utilized in the winter. In addition, the hydrogen needs to be available for use immediately. Since the plan is that the hydrogen will be used quite frequently, it is advantageous to establish a compressed hydrogen storage system. This in turn would create an opportunity to construct a refueling station that can fuel the system in a fast and efficient way.

An additional factor to evaluate is the maintenance of the storage system. Since Kirkenes is a relatively small town it has a limited capacity of workers and working hours. The storage system must therefore be able to run on its own for periods of time, without the need for supervision and maintenance. Establishing supporting batteries in addition to hydrogen production should also be considered. Batteries are able to provide instantaneous backup during energy shortages.

However, they are only able to support the system for a short time. This means that a setup of lithium-ion or flow batteries alone can not support the grid for longer periods of time. This makes the option of solely relying on batteries unfeasible. However, it can be a valuable factor in addition to an established hydrogen system.

An important factor in the discussion to integrate a small-scale hydrogen system is economic sustainability. When a PEM-electrolyser and a PEMFC are chosen as technology, the price of the system increases by approximately 30 MNOK. This is a huge cost for a project like this, and makes the system 60% more expensive than using an 8 MWh Lithium-ion battery as the storage unit. As mentioned in chapter 4.9, the prices for hydrogen technology are expected to drop significantly over the next decade, making this technology more sustainable and more affordable. If green hydrogen systems are able to produce hydrogen at a price down to 1 USD/kg, the system sails up as a both financial and sustainable project. The possible support solutions from state-owned associations will contribute and possibly make this a highly possible solution.

At the same time, as the push for sustainable development gains momentum in society, there is a growing emphasis on incorporating environmentally friendly solutions. Such systems have been shown to significantly reduce the environmental impact, and similar projects have demonstrated the potential for substantial reductions in greenhouse gas emissions. With the former system being driven by now illegal oil boilers and electric boilers, the reduction within this sector will be tremendous.

In the future, it may be possible to develop the energy storage system in the Nothing Hill project further by integrating batteries. One of the best options would be to use a combined battery and electrolysis system. This would give an option to storing the excess produced energy in the batteries and then use it to produce green hydrogen. This would therefore maximize the energy captured from wind and solar, as the battery never fills up and the electrolyser is very flexible to change in production. By doing this, green hydrogen can be produced when there is a surplus of power generation, while the ability to push back power into the grid when there is a shortage of energy. This makes it possible to buy electricity when the price is low and then convert it into hydrogen at a low cost. The system can switch back and forth between hydrogen production and battery discharging depending on the electricity prices to maximize profit.

One additional advantage of using supporting batteries for hydrogen production is that it will reduce the size of the fuel cell and electrolyser compared to a pure hydrogen system. As seen in the financial comparison in table 4.9, a battolyser consisting of an alkaline-electrolyser, PEMFC, and 1,4 MWh Li-ion battery would be approximately 2 200 000 NOK cheaper than a pure hydrogen system of just an alkaline-electrolyser and PEMFC. This is a result of decreasing the size of the electrolyser, fuel cell, and battery. This will reduce the overall cost of the system. While a pure hydrogen setup generally incurs higher installation and maintenance costs than a pure battery setup, the battolyser will not have increased costs for maintenance, thus providing an explanation for the overall cost-effectiveness of the system.

6.3 Carbon-negative village

For the area to go under the definition of a carbon-negative village the greenhouse emissions need to be balanced out by the amount it takes away. It is important to acknowledge that the calculations in this report are based solely on the old hospital, without considering the surrounding buildings. Therefore, the criteria for achieving a carbon-negative village will not be met. However, it is still possible for the main building to qualify as carbon-negative if the specified criteria are fulfilled. It complicates the calculations when it is an old building that is being renovated, instead of putting up a new building. For the old hospital in the Nothing Hill project, the estimated materials used in the structure are impossible to integrate in such an analysis, because the building has been around for many decades. With low standards within the energy sector at that time, the methods used have most likely been very little carbon-friendly. Therefore, it is difficult to say if this building is ever going to be carbon-negative. However, the building can be categorized under several other definitions within the green category. The proven cases give a good indication of how the system could look in different scenarios.

If the Nothing Hill project is able to cut almost 70% of its energy demand from 2021, the building would then be self-served with the amount of energy calculated in this report. The excess energy produced on net-positive days will be stored through a hydrogen process, with a total loss of 40,5% from produced to reused. In 2021 the project was in the start-up phase, meaning the old hospital was not nearly housing the same traffic as it will do when in full use. Despite the building's low energy activity in 2021, it required excessive energy consumption for non-essential purposes due to its poor condition. The project involves significant restoration work on the building, which is common for older structures that tend to consume unnecessary energy due to poor insulation. With the inclusion of geothermal heat and a fuel cell, the waterborne heat system avoids being heated by an electric boiler or worse, oil boilers. The heat demand consists of about 44% of the consumption in these types of buildings, and this part could then be covered by these mechanisms. This makes the reduction of electricity consumption a bit easier, but a huge drop in demand like this is still a difficult task to fulfill without tearing the building apart.

An energy-plus building is a building that produces more energy than it uses throughout the year. This is a possibility for the main building in the Nothing Hill project, the old hospital. For the building to achieve this definition, the energy consumption has to be below 1980 MWh during a year-span, making it consume only 90 kWh/m^2/year. This is 65,4% below the average building in this category, but it is still almost three times more than the consumption of the Brattørkaia Powerhouse. This is an example of a near perfect building with modern technology, built in 2019. The old hospital building in the Nothing Hill project was built in 1955 when the energy requirements were nonexistent and the technology was not nearly developed to the same grade. Even though a large part of the building will be renewed it is almost impossible to achieve the same standard as a newly built building, but it is still possible for the main building to produce energy in surplus, thus becoming an energy-plus building. In this case, the usage of the excess energy produced during the summer is a complicated part of the process that needs to be handled.

It is a possibility to sell energy to the grid, which is a viable option to be able to sustain a reliable energy network for the system. The complication arises because the Kirkenes area, located so far north in Norway with a relatively small population, generates more energy than it consumes. Therefore, there is no market to sell the surplus energy produced during the summer months, as there is no demand for it. Hydrogen is used in order to store so this energy is not wasted. If the Nothing Hill project was built in an area where the energy demand was higher, the most logical, in financial terms, would be to sell the excess energy back to the grid. As calculated, almost 60% of the excess energy is lost when storing it as hydrogen. This is the reason why an interplay with the grid would be largely beneficial and likely provide better financial results.

During a 24-hour period in January, the energy production can be as low as 42,20 kWh. This is a very small amount compared to the relative energy consumption in the building at the same time. It will therefore require a huge amount of electricity generated from the fuel cell. For a day like this, around 260 kg of hydrogen is required, which means that the tank that was originally proposed is too small in the project. In order to cover the electricity demand on all the days with an energy deficit, the tank must be half the size of an Olympic swimming pool. This is if the building is self-served. The other scenarios require much more hydrogen in order to cover the demand. During the summer, the stored excess energy in a day could become up to 6953 kWh, which equals 206.9 kg of hydrogen. In this scenario, the tank will fill up in 2 days, and the excess energy the next days will go to waste. Therefore a combination of several solutions seems to be most suitable for a sustainable energy system.

6.4 Sources of error

In almost every realistic calculation there are some factors that can lead to errors. When conducting an uncertainty analysis there are several factors to consider. In the beginning, it is important to identify the sources of errors and estimate how big an impact each one has. There are not many similar projects in the world to compare with where an old building is renewed and then self-served with energy. In this project, the energy produced is the most important and biggest calculation, and it consists of energy produced from the PV panels and the wind turbines. Both of these calculations are theoretical, and there are no test data yet to confirm whether the results are reliable.

To streamline the report, certain assumptions were necessary. For energy production, various sources of errors related to solar and wind power were included. However, due to the limitations of the calculations, it was not possible to include all of these factors. This may result in some level of uncertainty in the presented results, with one example being the impact of the albedo effect. As a result, the required reduction in energy consumption to achieve the desired outcomes, such as a positive energy building or carbon-negative community, may be greater than what is presented in the report. The estimation of solar energy production is somewhat uncertain due to reliance on optimal tilt angles. Achieving this number requires panels to be equipped with sun-tracking motors. However, it is possible that some panels may need to be installed at fixed angles, which could result in a reduction in energy output.

It also raises the question if the results would have been different and more realistic with data from the planned weather station and test panels instead. The weather, wind, and irradiation in Kirkenes are quite unstable and vary from week to week. Such instruments would have provided updated data that could be used to compare with the calculated results. An interesting point would be to see if there are any major differences in energy production on certain days and periods of the year.

In the calculations of the energy balance of the building, the heat demand has been assumed to be covered by geothermal energy. Whether this is going to be the case or not has not been decided by the company yet. It is possible for geothermal energy to cover the heat demand, but a large geothermal system will also bring complications. This is not included in the present report. The energy consumption in 2021 has the heating demand included since the heating was done by electric boilers. The building was not in use, so it is difficult to say how much energy went to electric devices versus heating. All the consumption data is based on the energy used in 2021 when the building was unoccupied. The energy demand will most likely be higher, which means that the building has to reduce consumption even more in order to reach TEK17 standards. If the building is going to be self-served, it is likely that the heating must be fully covered by geothermal energy, in addition to implementing other innovative solutions which bring down the electricity demand.

6.5 Further investigations

Because of the size of the Nothing Hill project, there are still unfinished tasks within the energy department, which can be worked on further. The project is only in its start-up phase, which means that several investigations need to be done to make further progress in the project. The investigations will depend on whether the project will be self-served, an energy-plus house, and if it will reach TEK17 standards. However, for all scenarios, the building would have to be renovated and reduce the total energy demand. This brings investigations like whether to use smart lights or not, which isolation materials are the best, and determining if the building should be able to reuse heat. These are just some examples, however, several other facts can be evaluated. The geothermal heat system will be incredibly important if the building is ever going to be self-served or an energy-plus house. The implementation combined with waterborne heat would be an important, key investigation. Many of these tasks are very suitable for a potential master's thesis.

As mentioned, updated data obtained from the PV test panels and weather station will also lead to improved and more accurate calculations. The test panels were delivered a little too late to get any realistic irradiation data for the calculations. However, we received news and pictures at the end of the writing period that the panels had arrived. As one can see in figure 6.1, the PV test panels are now mounted in the desired optimal location, facing south.

Figure 6.1: Test PV panels on the rooftop

7 Conclusion

The potential production of energy through renewable sources in the Nothing Hill project was calculated to be 1980 MWh/year. The energy produced from the PV panels makes up 99,3% of the total production, which means that the energy contribution from the wind turbines is almost negligible. Kirkenes is located above the arctic circle with a midnight sun and cold climate, and the temperature has a huge impact on the amount of energy produced. The efficiency of the solar panels increase by 0,35% for each degree of temperature decrease, which led to a total of 24,7% higher calculated production compared to the calculations without temperature correction. The location had a significant impact on the difference in the amount of energy produced in the summer and winter. The total production on a typical sunny day was estimated to be 12 356 kWh, while in the winter season, the production was estimated to be as low as 42,2 kWh. To be able to utilize the generated energy whenever the consumption is higher than the production, an efficient energy storage system is required.

Hydrogen storage was evaluated as the best-suited energy-storing method for the Nothing Hill project. This was due to the need for seasonal storage, from production in the summer to utilization in the winter. Hydrogen is a storage method that performs well in terms of high specific energy density and long-term cost, which is important for long-term storage. The current plan is to build a pure hydrogen system. However, in the future, the incorporation of supporting batteries should be considered as an option. Batteries will reduce the total cost and improve the interplay of the energy system by complementing the hydrogen system, making it more flexible.

To be able to achieve year-round self-sufficiency in energy supply using hydrogen as a storage method, the building in the Nothing Hill project must reduce its energy consumption by 70% reduction compared to 2021. The process of producing hydrogen through electrolysis, compressing it, and utilizing it in a fuel cell has an overall efficiency of 40.5%. However, there are additional challenges to address, such as the size of the storage unit needed to meet the energy demands during the winter months and the associated costs of implementing the system. Today, this is not an economically sustainable solution. Nevertheless, with financial support from governmental associations and continued reduction in system costs, it holds the potential to become a viable option in the future.

Collaborating with the main grid combined with an energy storage system seems to be the optimal approach for the project. This strategy offers opportunities to optimize both financial and technical aspects, by avoiding the need for a storage unit as large as a swimming pool while ensuring that the already overloaded grid is not further overwhelmed.

It is highly unlikely that the village will meet the criteria for being classified as carbon-negative. This is primarily due to the inherent challenges in accounting for the materials used during the building process in 1955. However, there is a potential for the building to meet other sustainable classifications. To achieve an energy-plus operation the energy consumption needs to be reduced by 51.1% compared to the 2021 data. Considering the building is currently not in use, this reduction may need to be even more substantial. To accomplish such a reduction, it is essential to implement innovative solutions and restore the structure of the building in a manner that minimizes carbon emissions as much as possible.

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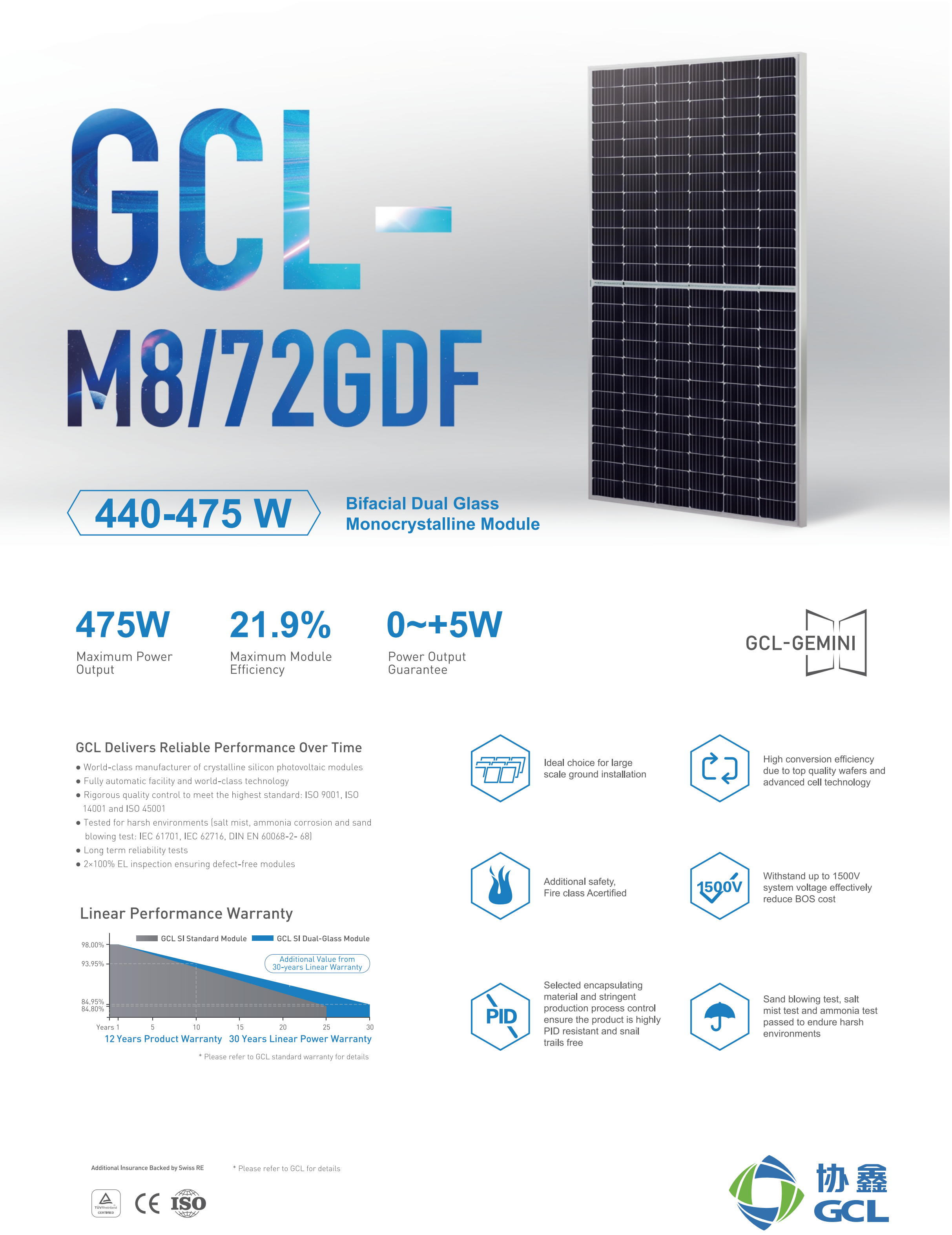
A Appendix A: Solar Panel Data-Sheet



GCL-
M8/72GDF

440-475 W

**Bifacial Dual Glass
Monocrystalline Module**

475W	21.9%	0~+5W
Maximum Power Output	Maximum Module Efficiency	Power Output Guarantee

GCL-GEMINI

GCL Delivers Reliable Performance Over Time

- World-class manufacturer of crystalline silicon photovoltaic modules
- Fully automatic facility and world-class technology
- Rigorous quality control to meet the highest standard: ISO 9001, ISO 14001 and ISO 45001
- Tested for harsh environments (salt mist, ammonia corrosion and sand blowing test: IEC 61701, IEC 62716, DIN EN 60068-2- 68)
- Long term reliability tests
- 2×100% EL inspection ensuring defect-free modules

Linear Performance Warranty

12 Years Product Warranty 30 Years Linear Power Warranty

* Please refer to GCL standard warranty for details

Ideal choice for large scale ground installation

High conversion efficiency due to top quality wafers and advanced cell technology

Additional safety, Fire class Acertified

Withstand up to 1500V system voltage effectively reduce BOS cost

Selected encapsulating material and stringent production process control ensure the product is highly PID resistant and snail trails free

Sand blowing test, salt mist test and ammonia test passed to endure harsh environments

Additional Insurance Backed by Swiss RE

* Please refer to GCL for details

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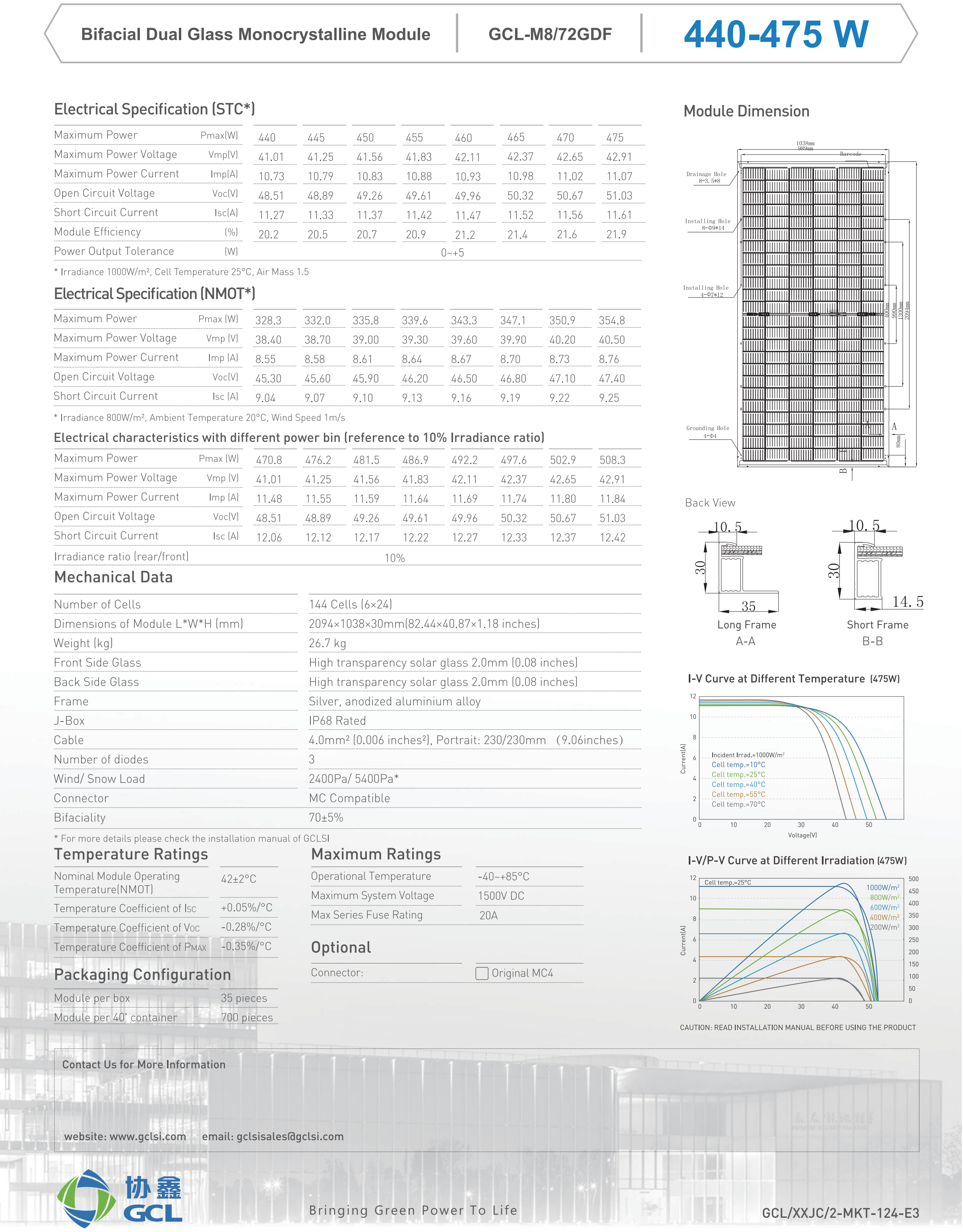
A APPENDIX A: SOLAR PANEL DATA-SHEET



Bifacial Dual Glass Monocrystalline Module | **GCL-M8/72GDF** | **440-475 W**

Electrical Specification (STC*)

Maximum Power	Pmax(W)	440	445	450	455	460	465	470	475
Maximum Power Voltage	Vmp(V)	41.01	41.25	41.56	41.83	42.11	42.37	42.65	42.91
Maximum Power Current	Imp(A)	10.73	10.79	10.83	10.88	10.93	10.98	11.02	11.07
Open Circuit Voltage	Voc(V)	48.51	48.89	49.26	49.61	49.96	50.32	50.67	51.03
Short Circuit Current	Isc(A)	11.27	11.33	11.37	11.42	11.47	11.52	11.56	11.61
Module Efficiency	(%)	20.2	20.5	20.7	20.9	21.2	21.4	21.6	21.9
Power Output Tolerance	(W)	0~+5							

* Irradiance 1000W/m², Cell Temperature 25°C, Air Mass 1.5

Electrical Specification (NMOT*)

Maximum Power	Pmax (W)	328.3	332.0	335.8	339.6	343.3	347.1	350.9	354.8
Maximum Power Voltage	Vmp (V)	38.40	38.70	39.00	39.30	39.60	39.90	40.20	40.50
Maximum Power Current	Imp (A)	8.55	8.58	8.61	8.64	8.67	8.70	8.73	8.76
Open Circuit Voltage	Voc(V)	45.30	45.60	45.90	46.20	46.50	46.80	47.10	47.40
Short Circuit Current	Isc (A)	9.04	9.07	9.10	9.13	9.16	9.19	9.22	9.25

* Irradiance 800W/m², Ambient Temperature 20°C, Wind Speed 1m/s

Electrical characteristics with different power bin (reference to 10% Irradiance ratio)

Maximum Power	Pmax (W)	470.8	476.2	481.5	486.9	492.2	497.6	502.9	508.3
Maximum Power Voltage	Vmp (V)	41.01	41.25	41.56	41.83	42.11	42.37	42.65	42.91
Maximum Power Current	Imp (A)	11.48	11.55	11.59	11.64	11.69	11.74	11.80	11.84
Open Circuit Voltage	Voc(V)	48.51	48.89	49.26	49.61	49.96	50.32	50.67	51.03
Short Circuit Current	Isc (A)	12.06	12.12	12.17	12.22	12.27	12.33	12.37	12.42
Irradiance ratio (rear/front)		10%							

Mechanical Data

Number of Cells	144 Cells (6×24)
Dimensions of Module L*W*H (mm)	2094×1038×30mm(82.44×40.87×1.18 inches)
Weight (kg)	26.7 kg
Front Side Glass	High transparency solar glass 2.0mm (0.08 inches)
Back Side Glass	High transparency solar glass 2.0mm (0.08 inches)
Frame	Silver, anodized aluminium alloy
J-Box	IP68 Rated
Cable	4.0mm² (0.006 inches²), Portrait: 230/230mm （9.06inches）
Number of diodes	3
Wind/ Snow Load	2400Pa/ 5400Pa*
Connector	MC Compatible
Bifaciality	70±5%

* For more details please check the installation manual of GCLSI

Temperature Ratings

Nominal Module Operating Temperature(NMOT)	42±2°C
Temperature Coefficient of Isc	+0.05%/°C
Temperature Coefficient of Voc	-0.28%/°C
Temperature Coefficient of Pmax	-0.35%/°C

Packaging Configuration

Module per box	35 pieces
Module per 40' container	700 pieces

Maximum Ratings

Operational Temperature	-40~+85°C
Maximum System Voltage	1500V DC
Max Series Fuse Rating	20A

Optional

Connector:	☐ Original MC4

Module Dimension

Back View

Long Frame
A-A

Short Frame
B-B

I-V Curve at Different Temperature (475W)

I-V/P-V Curve at Different Irradiation (475W)

CAUTION: READ INSTALLATION MANUAL BEFORE USING THE PRODUCT

Contact Us for More Information

website: www.gclsi.com email: gclsisales@gclsi.com

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Bringing Green Power To Life

GCL/XXJC/2-MKT-124-E3

B Appendix B: Wind Turbine Data-Sheet

RW500 Wind Turbines

EXTREMELY DURABLE
NO NEED TO FACE WIND
PRODUCTION IN LOW AND HIGH WIND
SILENT OPERATION
EASY TO INSTALL

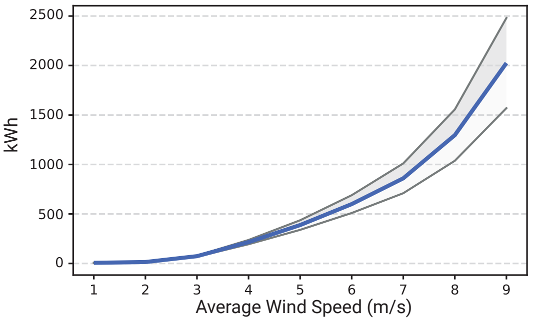
www.icewind.is
info@icewind.is
+354 861-2011

IceWind designs and manufactures robust micro vertical-axis wind turbines and other hybrid energy solutions to power telecom towers, weather and seismic stations, and on-grid and off-grid lodgings. All products are designed and tested in Iceland, one of the windiest places on earth.

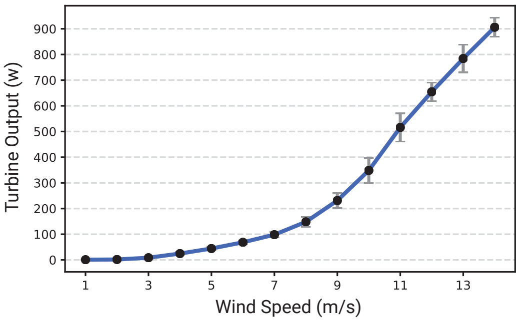
RW series vertical-axis wind turbines are built to be mounted directly on commercial or military telecom towers, communication depots, relay station, and radar outposts, reducing operational costs, and increasing backup power time. RW turbines are designed to deliver long lasting performance, with little or no maintenance for over 20 years. They are able to withstand wind speeds up to 135 mph (Category 4 Hurricane wind speeds) and will consistently deliver power, even in the harshest conditions such as snow, ice and sand storms.

RW500

Survival speed	*135 mph*	60 m/s
Startup wind speed	4.5 mph	2 m/s
Cut in wind speed	5.5 mph	2.5 m/s
Rated power	500 W	
Max power	3000 W	
Rated wind speed	22 mph	10 m/s
Noise level	< 30 dB	
Height	86 inch	2.2 m
Diameter	51 inch	1.3 m
Weight	187 lbs	85 kg
Generator	*2 x 500 W AFPMG*	
Number of blades	*3 Inner, 3 Outer*	



Annual RW500 Output



RW500 Power Curve

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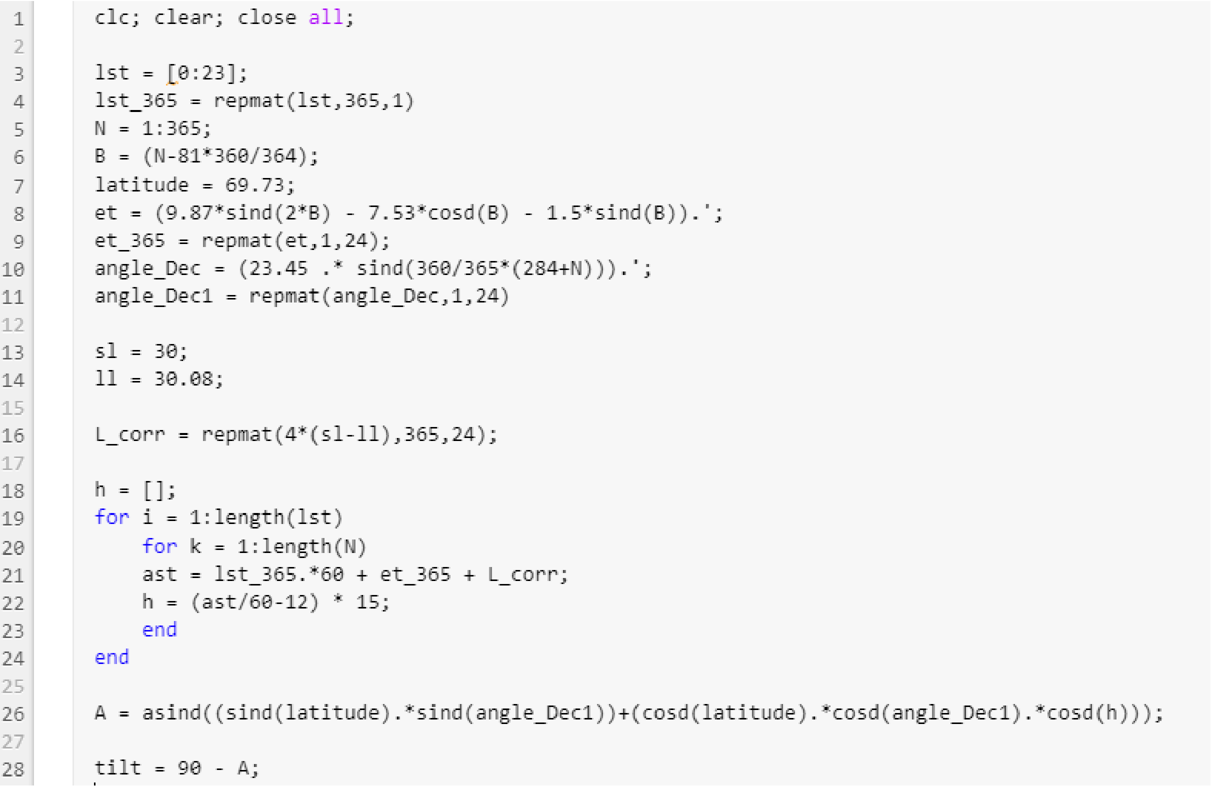
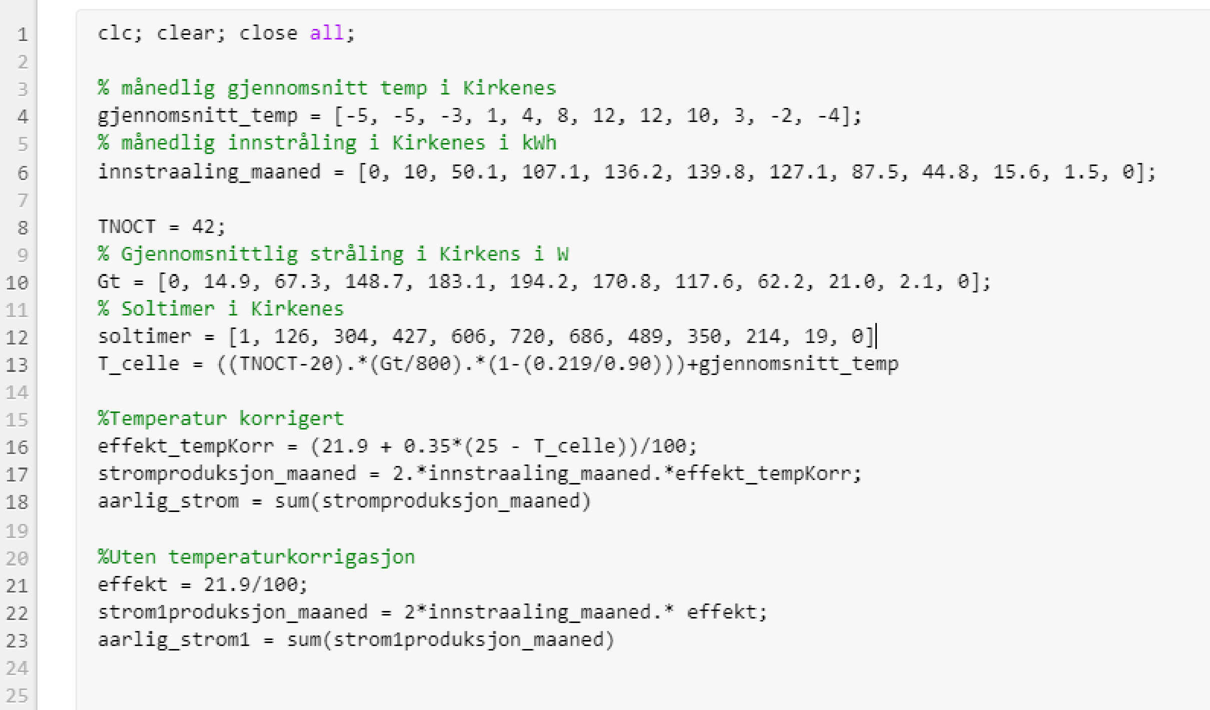
C Appendix C: Tilt Angle Matlab



```matlab
clc; clear; close all;

lst = [0:23];
lst_365 = repmat(lst,365,1)
N = 1:365;
B = (N-81*360/364);
latitude = 69.73;
et = (9.87*sind(2*B) - 7.53*cosd(B) - 1.5*sind(B)).';
et_365 = repmat(et,1,24);
angle_Dec = (23.45 .* sind(360/365*(284+N))).';
angle_Dec1 = repmat(angle_Dec,1,24)

sl = 30;
ll = 30.08;

L_corr = repmat(4*(sl-ll),365,24);

h = [];
for i = 1:length(lst)
    for k = 1:length(N)
    ast = lst_365.*60 + et_365 + L_corr;
    h = (ast/60-12) * 15;
    end
end

A = asind((sind(latitude).*sind(angle_Dec1))+(cosd(latitude).*cosd(angle_Dec1).*cosd(h)));

tilt = 90 - A;
```

D Appendix C: Solar Energy Yield Matlab



```
clc; clear; close all;

% månedlig gjennomsnitt temp i Kirkenes
gjennomsnitt_temp = [-5, -5, -3, 1, 4, 8, 12, 12, 10, 3, -2, -4];
% månedlig innstråling i Kirkenes i kWh
innstraaling_maaned = [0, 10, 50.1, 107.1, 136.2, 139.8, 127.1, 87.5, 44.8, 15.6, 1.5, 0];

TNOCT = 42;
% Gjennomsnittlig stråling i Kirkens i W
Gt = [0, 14.9, 67.3, 148.7, 183.1, 194.2, 170.8, 117.6, 62.2, 21.0, 2.1, 0];
% Soltimer i Kirkenes
soltimer = [1, 126, 304, 427, 606, 720, 686, 489, 350, 214, 19, 0]
T_celle = ((TNOCT-20).*(Gt/800).*(1-(0.219/0.90)))+gjennomsnitt_temp

%Temperatur korrigert
effekt_tempKorr = (21.9 + 0.35*(25 - T_celle))/100;
stromproduksjon_maaned = 2.*innstraaling_maaned.*effekt_tempKorr;
aarlig_strom = sum(stromproduksjon_maaned)

%Uten temperaturkorrigasjon
effekt = 21.9/100;
strom1produksjon_maaned = 2*innstraaling_maaned.* effekt;
aarlig_strom1 = sum(strom1produksjon_maaned)
```