Kjell Petersen Synstad, Halvor Bratvold Ekren and Martin Wirak Onsrud

Modelling a Hybrid Energy System with Micro Hydropower for a ZEB Fulfilling the FutureBuilt Standard

The Energy System of Skavanger School

Bachelor's project in Renewable Energy
Supervisor: Pauline Zimmermann, Odne Stokke Burheim and Pål Preede Revheim

May 2020

Bachelor's project

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Energy and Process Engineering

NTNU
Kunnskap for en bedre verden

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Preface

This bachelor thesis is the culmination of three years at the Renewable Energy study programme at NTNU (*Norges teknisk-naturvitenskaplig universitet*). This thesis is written in cooperation with Sweco Norge, the Norwegian branch of the multinational consultancy company Sweco. One of Sweco's projects was to investigate and provide reports on micro hydropower and thermochemical energy storage for Kongsberg municipality. Our first meeting with Pål Preede Revheim, the external supervisor from Sweco Norge, was on the 28^{th} of October 2019. From that meeting, we started working on the thesis statement based on the project Sweco was working on. The project concerns a school in Kongsberg that is being rebuilt to meet the passive house standard while fulfilling the criteria for a FutureBuilt building. In collaboration with Pål, we formulated a thesis statement regarding the school's energy system based on a combination of Sweco's and our interests.

Over the last three years we have acquired knowledge from a variety of topics throughout our study programme. Applying this knowledge on a real life project and being able to base a bachelor thesis on it, has been highly educational. Overall, the period working on the thesis has been entertaining and interesting. However, it has also been challenging and frustrating at times. The process we have gone through has taught us a lot, and we are grateful for all the experiences from this semester.

There are several people we want to thank for their contributions to our thesis. Firstly, we want to thank Energy Engineer Hallvard Benum and Kongsberg kommunale eiendom for providing us with information about the project and allowing us to write this bachelor thesis.

We would like to thank our external supervisor, Senior Energy Consultant Pål Preede Revheim from Sweco Norge. He has been crucial with his guidance and for providing information throughout the semester, as well as helping us develop a thesis statement. His contributions and interest in our work is deeply appreciated.

We also want to thank our internal supervisors at NTNU, PhD Candidate Pauline Zimmermann and Professor Odne Stokke Burheim. Their advice and feedback have been very valuable to us. They have guided and helped us, leading to an improved final product.

For helping us get a better understanding of the load profile for the school, we would like to the Karen Byskov Lindberg for sharing her knowledge on the topic.

For his contributions over the past three years at the study programme Renewable Energy, Study Programme Leader Håvard Karoliussen deserves great recognition. His work as a lecturer and for his efforts on improving the study programme, both educationally and socially is highly appreciated. Our time in studying in Trondheim would not have been the same without him.

Trondheim, 22.05.2020

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Abstract

To achieve the 2 °C goal set by the Paris Agreement, the global building and construction sector has to cut its CO_2e emissions by 60 % in 2050 compared to the 2012 level [1]. This sector accounts for approximately 19 % of energy-related greenhouse gas emissions [1,2] and in Norway, 40 % of the total energy usage comes from buildings [3]. One solution that can help alleviate this challenge, is the increased investment in Zero Emission Buildings (ZEB).

The objective of this thesis is to investigate different combinations of micro hydropower, solar power and batteries, to find a favourable energy system for Skavanger School. Self sufficiency, lifetime cost and fulfilling the FutureBuilt standard were the main focus areas for this energy system. FutureBuilt is a building standard where in addition to being a ZEB, the building has to produce a certain amount of electricity locally. Since the energy system at this school will include a micro hydropower plant of 28 kW, which is unusual for ZEBs, this thesis could provide results that could be useful for similar projects in the future.

Seven scenarios were created with different combinations of a hydropower plant, solar PV panels and battery capacity. A simulation was run for all scenarios, looking at power demand and solar power production, while regulating the hydropower production to fit the power demand for the school. In addition to this, scenarios with only solar PV panels, and only hydropower were simulated. The costs were calculated with a low, medium and high spot price to see the effect on lifetime costs when varying the electricity prices. Results produced from the simulation includes lifetime cost, self sufficiency with and without battery in addition to electricity bill, among others. In addition to this, several graphs showing weekly and yearly data from the results were created for the different scenarios.

The scenarios that gave the most favourable results were the scenarios with a 28 kW hydropower plant and a 150 kWh battery (Hydro-A) in addition to the scenario with 600 m^2 of solar PV panels, a 28 kW hydropower plant and a 75 kWh battery (2-B). These scenarios had a high self sufficiency, in addition to relatively low lifetime costs. Hydro-A has a self sufficiency of 98.38 % and has the lowest lifetime costs of all the scenarios assuming medium spot prices. Scenario 2-B has a self sufficiency of 97.94 % and has the lowest lifetime cost if the spot prices are higher. The scenario with 959 m^2 of solar PV panels, 150 kWh of battery and hydropower (1-A) reaches a self sufficiency of 99.48 %, but comes with higher lifetime cost. The scenario with the worst performance was the one with only 959 m^2 of solar PV panels (scenario Original), with a self sufficiency of 32.73 % and the highest lifetime cost.

Sammendrag

For å oppnå 2-gradersmålet fra Parisavtalen, må byggenæringen kutte 60 % av sine CO_2e-utslipp innen 2050, sammenlignet med nivået i 2012. Globalt står byggenæringen for omtrent 19 % av energirelaterte drivhusgassutslipp [1,2] og i Norge kommer 40 % av energiforbruket fra bygninger. Nullutslippsbygninger (ZEB) kan være en del av løsningen for å oppnå målene om redusert utslipp.

Målet for denne oppgaven er å undersøke forskjellige kombinasjoner av mikrovannkraftanlegg, solcellepanel og batterier for energisystemet på Skavanger skole. Oppgaven har et fokus på høy grad av selvforsynthet fra strømnettet og lave livsløpskostnader, samtidig som FutureBuilt kravet opprettholdes. FutureBuilt er en byggestandard som går over passivhusstandarden ved å kreve at bygget produserer en viss mengde elektrisitet i året. Energisystemet inkluderer et mikrovannkraftanlegg på 28 kW, noe som er uvanlig å benytte sammen med ZEB. Resultatene fra oppgaven kan bidra til økt kunnskap som kan brukes ved liknende prosjekter i fremtiden.

Syv forskjellige scenarioer med ulike kombinasjoner av mikrovannkraftanlegg, solcelleareal og batterikapasitet ble laget, og en simuleringsmodell ble utviklet for å teste scenarioene. Simuleringen ble kjørt for alle scenarioene, der det ble sett på energibehov og produksjon fra solcellene, mens vannkraftverket ble regulert basert på gjenstående behov. Det ble også sett på energisystem bestående av kun solkraft og kun vannkraft. Energisystemet ble simulert med med en lav, middels og høy spotpris for å undersøke hvordan forskjellige strømpriser påvirker livsløpskostnadene. Resultater fra simuleringen inkluderer blant annet livsløpkostnader, selvforsynthet med og uten batteri og strømregningen for energisystemet. Dette er også visualisert i grafer for en gitt uke og over et helt år.

Scenarioene med de mest gunstige resultatene var scenarioet med 28 kW vannkraft og 150 kWh batterykapasitet (Hydro-A), samt scenarioet med 600 m^2 med solceller, 28 kW vannkraft og 75 kWh batterikapasitet (2-B). Disse scenarioene har høy selvforsynthet og relativt lave livsløpskostnader. Scenario Hydro-A har en selvforsynthet på 98.38 %, samt de laveste livsløpkostnadene av samtlige scenarioer. Hydro-A er ansett som det beste scenarioet dersom spotprisene ligger på et middels nivå. Scenario 2-B har en selvforsynthet på 97.94 % og har lavest livsløpkostnader dersom spotprisene er på det høyeste nivået. Scenarioet med høyest selvforsynthet er scenario 1-A. Dette scenarioet har 959 m^2 med solceller, 150 kWh batterikapasitet og 28 kW vannkraft og når 99.48 % selvforsynthet, men har høyere livsløpkostnader enn de øvrige scenarioene. Det scenarioet som har dårligst selvforsynthet er scenario Original, som består av kun 959 m^2 med solceller. Scenarioet har de høyeste livsløpkostnadene og en selvforsynthet på 32.37 %.

Contents

List of Terms

Azimuth	A horizontal direction, given in degrees measured clockwise from a north base line.
CO_2e emissions	Carbon dioxide equivalent emission is a measurement for comparing the warming potential of different greenhouse gasses.
Discharge	Two definitions. The first is the cross-section of water in the direction of motion multiplied with the velocity, also known as volumetric flow rate [m^3/s]. The second is battery discharge which is a chemical reaction generating electricity [kWh].
Depletion Zone	An insulating region within a conductive, doped semiconductor material where the mobile charge carriers have been diffused away, or have been forced away by an electric field. Found inside a solar panel.
End Users	The users of produced power, transmitted trough the power grid.
Greenhouse Gas Emissions	The gasses which absorb and give off the heat energy emitted by the Earth. Greenhouse gasses have a warming effect on the planet.
Infiltration losses	Heat loss from air leakage through joints and cracks in buildings, often found around windows and doors.
Inflow	Water added to the reservoir from precipitation, ground flow streams and other natural sources.
N-Type	A negatively charged silicon wafer used in solar photovoltaic cells.
Nord Pool	A power market and trading company. Operating as the nominated electricity market operator in 15 countries.
NS 3700	Norwegian passive house standard for residential buildings.
NS 3701	Norwegian passive house standard for non-residential buildings.
Prosumer	An end user that both consume and produce electricity.
System Loss	Power loss from what is produced by the solar PV cells to what is actually delivered to the grid.
TEK17	Regulations on technical requirements for construction works.
The Paris Agreement	The Paris agreement is a joint agreement with most of the worlds nations that includes the goal to keep the increase in global temperature to well below 2 °C above pre-industrial levels.
Thermal Bridge	A thermal bridge, also called a cold bridge, heat bridge, or thermal bypass, is an area or component of an object which has higher thermal conductivity than the surrounding materials, creating a path of least resistance for heat transfer.

Thermal Transmittance	Thermal transmittance is the rate of transfer of heat through matter. Also known as U-value.
Transmission losses	Loss in power from transmitting electricity over a distance.
P-Type	A positively charged silicon wafer used in solar photovoltaic cells.
Self Sufficiency	A measure how much of the electricity need that comes from locally produced power per hour over a year.
SIMIEN	A dynamic simulation program for buildings.
Price Sensitivity	Describes how much the profitability of the energy system changes with varying spot prices.

List of Symbols

Symbol	Unit	Description
θ_{ym}	°C	Annual mean temperature
β	kWh/m^2°C	Factor used to calculate maximum energy used for cooling
A_fl	m^2	Total floor area
C_e	NOK/kWh	Cost of buying power from the power supplier per kWh
$C_{g,f}$	NOK	Fixed grid rent charged by grid operator
$C_{g,v}$	NOK/kWh	Energy tariff charged by the grid operator per kWh
C_p	NOK/kW	Power tariff
C_{rate}	NOK/kWh	Rate for how much the grid operator pays per kWh exported to the grid
C_{tax}	NOK	Tax levied by the Norwegian state per kWh used
C_{tot}	NOK	Total cost of electricity
DUT_s	°C	Design Outdoor Temperature, used to calculate maximum cooling in NS 3701
E_C	kWh/m^2	Maximum energy used for cooling per square meter per year
E_H	kWh/m^2	Maximum energy used for heating per square meter per year
$EP_{H,O}$	kWh/m^2	Tabulated value for maximum heating.
E_p(t)	kWh	Energy produced per hour t and energy pulled from the grid in hour t
E_u(t)	kWh	The amount of energy used in the hour t
E_{im}(m)	kWh	The amount of energy imported from the grid
E_{ex}(m)	kWh	The amount of energy exported to the grid
K_1	kWh/m^2°C	Tabulated value for maximum heating
S_s	%	Self sufficiency
t	h	The given hour for which calculations are being performed

Abbreviations

CO_2	Carbon Dioxide
DoD	Depth of Discharge
DUT	Design Outdoor Temperature
EU	The European Union
GIA	Gross Internal Area
Li-ion	Lithium Ion
NOK	Norwegian Kroner
NTNU	Norges teknisk-naturvitenskapelige universitet - Norwegian University of Science and Technology
NVE	Norges vassdrags- og energidirektorat - The Norwegian Water Resources and Energy Directorate
PV	Photovoltaic
PVGIS	Photovoltaic Geographical Information System
SFP	Specific Fan Power
UN	United Nations
UNEP	United Nations Energy Programme
ZEB	Zero Emission Building

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1 Introduction

In the years to come, the world has to go through an energy transition from fossil to renewable energy, while becoming more energy efficient. These visions have been formulated in the goals set by United Nations (UN) in the Paris Agreement. 196 states have signed this agreement on how to deal with greenhouse gas emissions in an attempt to not exceed a 2 °C increase of global average temperature compared to pre-industrial levels [4]. Buildings are massive polluters globally and an important step towards a sustainable society is to build ZEBs, which are buildings designed to reach net zero emissions over the lifetime of the building. This is often accomplished by offsetting the emissions associated with construction by producing renewable energy locally. [1]

Globally, the building and construction sector account for approximately 19 % of energy-related greenhouse gas emissions [1, 2]. In Norway, 40 % of the total energy usage comes from buildings [3]. This indicates that this sector has a lot of potential in regards to energy usage and CO_2e emissions. In a society, the investment in buildings and infrastructure correlates with increased public health and economic growth. Secondly, the estimations for the global population indicates an increase of 2.5 billion people by 2050 [2]. To invest and build for a well functioning society without increasing the greenhouse gas emissions, the sector has to cut its CO_2e emissions by 60 % in 2050 compared to 2012, to achieve the 2 °C goal set by the Paris Agreement [1]. This is where ZEB comes in as a solution, in addition to renovating and rehabilitation of existing buildings.

The Norwegian Government has developed new, stricter energy specifications to reduce the energy demand. Their calculations say that from 2020, when the new energy regulations are implemented, buildings will have a 1-1.2 TWh reduction of energy use per year. That is as much energy as 50 000 to 60 000 households use during a year, which is approximately equal to the size of the city of Stavanger. [3]

The 12th of September 2018 the municipal council of Kongsberg adopted the plan of building a new school at Skavanger which will be completed by the start of the 2021/2022 semester. The planned capacity of the school is 275 pupils with the possibility of an expansion. The school is going to be built in solid wood as a ZEB fulfilling FutureBuilt requirements. FutureBuilt is a building standard where in addition to meeting the passive house standard, energy production is also required. The specific magnitudes of the different components for the energy system has not been decided at the time of writing this thesis.

Rambøll, the consultancy company responsible for the initial energy calculations, estimated key numbers about the school's energy demand. The full report on this can be found in Appendix A. In turn, Sweco was hired to assess the possibilities to reduce the amount of solar PV cells, instead incorporating a micro hydropower plant.

The objective of this thesis is to investigate different combinations of the energy system at Skavanger School in Kongsberg municipality using the components micro hydropower, solar power and batteries. Self sufficiency, lifetime cost and fulfilling the FutureBuilt standard were the main focus areas. Since the energy system at this school will include a micro hydropower plant of 28 kW, which is unusual for ZEBs, this thesis could provide results that may be valuable for future similar projects.

1.1 Thesis Statement

With the integration of more renewable and distributed power generation and stricter building regulations, the energy landscape for the end-user is changing. With its multifaceted energy system which includes solar PV cells, micro hydropower and a battery, in addition to the energy efficiency dictated by the FutureBuilt standard, allows the Skavanger School project to be a window into what this may look like. As the price of electricity is projected to increase in the future, producing and utilising local power could be beneficial to lessen the end-users dependency on the power grid [5]. By being less dependent on the power grid, the school's electricity bill will be less affected by fluctuations in spot price.

This thesis' objective is to analyse the energy system at Skavanger School. By creating several scenarios, based on reports from Rambøll and Sweco, the performance of the system can be examined. The goal is to identify a configuration where the self sufficiency rate is high while the lifetime cost are low compared to the other scenarios. Because it is difficult to predict the future electricity prices, different prices of electricity will be used to examine how sensitive the scenarios are to spot price fluctuations. The thesis statement can be summarised as:

"Which of the scenarios of the energy system at Skavanger School has the most favourable combination of lifetime costs and self sufficiency, while maintaining the FutureBuilt requirements?"

To quantify what defines a *favourable combination*, the scenarios will be compared on the following criteria:

- Self sufficiency
- Total lifetime cost, with three different spot prices
- Price sensitivity

Using these parameters, the different scenarios will be compared to each other with the aim to identify the scenario with the best combination of the listed criteria.

2 The Energy System

From an energy production and consumption standpoint, Skavanger school consists of five elements. These elements are solar PV panels, a micro hydropower plant, batteries, the power grid and the school. The purpose for the energy system is to meet the school's electricity demand. This includes electricity used in e.g. ventilation, heating, cooling, lighting and other electrical components. Another central function of the energy system is to make it possible for the school to meet the energy production needed for the FutureBuilt standard.

Figure 2.1 illustrates how the different elements of the energy system at Skavanger School interact. In the figure, the boxes represent the elements and the black arrows represent the energy flow between them. The hydropower plant and the solar PV panels produce energy for the school's demand and for charging the battery. In addition to this, any excess production from the solar PV panels will be exported to the grid. If the school is experiencing a deficit of electricity, this needs to be supplied from either the battery or the grid. The production and consumption profiles vary over a year, leading to a change in the interactions and performance of the elements for different seasons. One example of this is during the summer as there may be a energy surplus from the solar PV panels, which can charge the batteries and also be exported to the grid. The opposite effect can be seen during the winter, as the cold climate leads to a demand for extra energy from the grid as the solar conditions are worse.

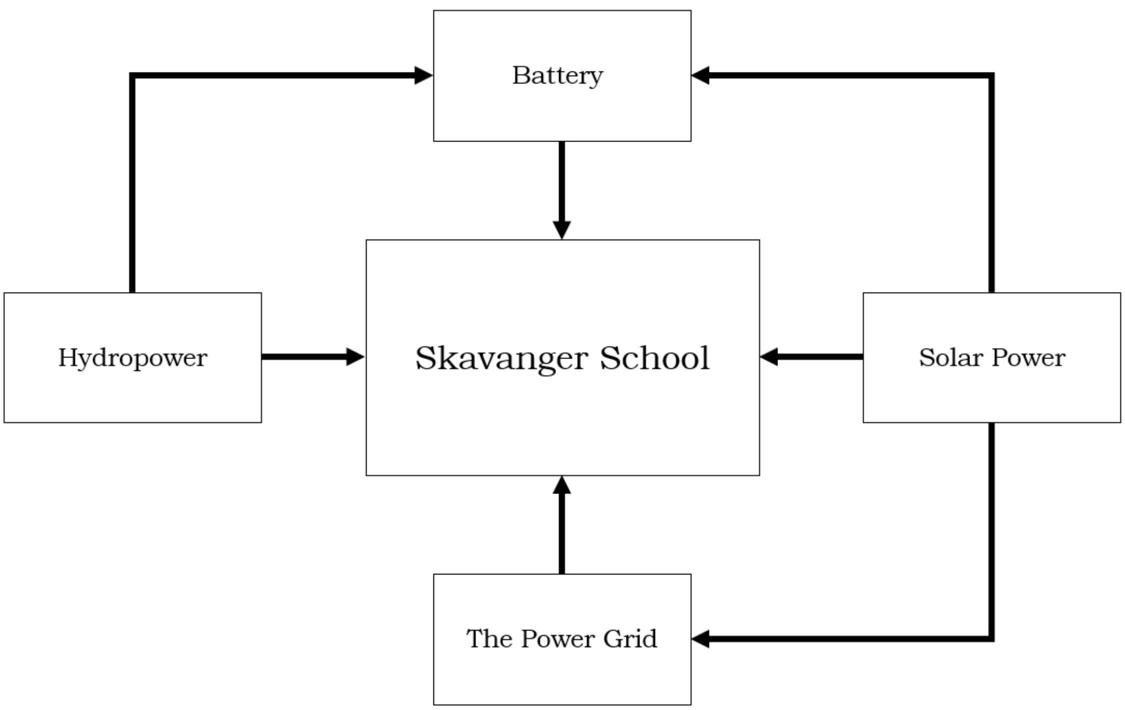

Figure 2.1: *A simplified visualisation of the energy system at Skavanger School. The energy system is divided in to five elements. The black arrows illustrate in which direction energy flows throughout the system.*

2.1 Specifications and Requirements for the FutureBuilt Standard

In 2016, the building and construction sector accounted for 19 % of the global greenhouse gas emissions and are projected to double by 2050, according to the United Nations Energy Programme (UNEP) [1]. Average electricity consumption used for heating in an European Union (EU) household, is between 2.5 and 5 MWh per year. For several of these countries, a greater portion of the heating comes from other energy sources such as gas and oil [6]. Meanwhile in Norway, the average household uses around 16 MWh electricity per year for heating [7]. This illustrates how the building sector in both Norway and the EU have a high consumption of energy. Reducing the consumption, in addition to having local power production is an important step in working towards a more sustainable society.

The FutureBuilt programme is an endeavour to accomplish reductions in emissions linked to construction and operation of buildings. The projects fulfilling the FutureBuilt standard are meant to inspire other projects to invest in new sustainable solutions while contributing to innovation and development of the construction sector. [8]

2.1.1 TEK17

In Norway, the minimum specifications needed to legally construct a building is outlined in the *Regulations on Technical Requirements for Building Works*, also known as *TEK17*. These regulations contain several different categories of requirements, such as fire safety, construction safety and documentation [9]. For this bachelor thesis, the most relevant chapter of TEK17 is Chapter 14, which contains specifications regarding energy.

In TEK17, subchapter 14-2 regarding energy efficiency, an upper limit for how much energy different types of buildings can use throughout a year is stated. The energy usage is measured in kWh/m^2 heated GIA pr year and for school buildings the limit is 11 kWh/m^2 heated GIA pr year [9]. GIA is short for Gross Internal Area and is the total area encompassed by the external walls of a building. The area taken by the internal walls are excluded.

Subchapter 14-3 in TEK17 provides minimum specifications of performance concerning thermal transmittance, also called U-value, for different parts of the building. Table 2.1, shows the different requirements for each segment of the building. For instance, the thermal transmittance for the outer walls have to be significantly lower than the windows and doors. U-values are given with the units kWh/m^2 heated GIA per year. The air leakage value is defined as the number of air shifts per hour with a 50 Pa pressure differential. One air shift occurs when the entire volume of air inside a building is changed trough for example ventilation. [9]

Table 2.1: *Minimum segment requirements for U-value and air leakage as specified in TEK17. [9]*

Segment	Requirement
U-value Outer Wall [kWh/m^2]	≤ 0.22
U-value Roof [kWh/m^2]	≤ 0.18
U-value Floor [kWh/m^2]	≤ 0.18
U-value Window and Door [kWh/m^2]	≤ 1.2
Air Leakage [h^{-1}]	≤ 1.5

TEK17 contains several paragraphs regarding the energy supply for the heating system in a building. These paragraphs are found in Subchapter 14-4. Paragraph (1) states that the building can not be heated with a system using fossil fuel. For buildings over 1000 m^2 GIA paragraph (2) applies. This paragraph have two clauses which state that the energy system for the heating system needs to be both flexible and use low temperature solutions. In TEK17, a flexible energy system is defined as an energy system where several sources can be used for heating. The different sources are not required to operate at the same time, but it needs to be possible to change the source of heating. Examples of low temperature solutions include the utilisation of waste heat, heat from the sun or heat from the surroundings. [9]

2.1.2 NS 3701

To fulfil the FutureBuilt requirements, a school building must first satisfy the passive house standard for non-residential buildings described in the Norwegian standard NS 3701. This standard has six central elements with requirements that must be attained. These include transmission losses, infiltration losses, energy requirements for heating, cooling and lighting, air flow and U-values. Several of the requirements in NS 3701 depends on the local annual mean temperature and building type. There are also different requirements for different types of buildings, e.g schools, hospitals, offices, etc. In NS 3701 the requirements differ based on what category of building is being built. A passive house building has stricter requirements compared to a low energy building. [10]

To limit the uncontrollable energy loss from heat leaking through the materials of the building, NS 3701 requires that the U-value representing these losses should be under a certain threshold. These losses are called infiltration and transmissions losses and their scale are limited by the annual mean temperature, the size of the building and the building category. As a result, the thermal transmittance is a tabulated value found in NS 3701. [10]

NS 3701 contains requirements about the maximum amount of energy that can be used for heating, cooling and lighting. The formula for calculating the max energy used for heating, E_H, is shown in Equation 2.1. Both $EP_{H,0}$ and K_1 are tabulated values which depend on the building standard and building type. θ_{ym} represents the annual mean temperature. $EP_{H,0}$ is the base amount of heating that can be used, while K_1 and θ_{ym} is used to account for the local climate. [10]

$$E_H = EP_{H,0} + K_1(6.3 - \theta_{ym}) \tag{2.1}$$

The maximum amount of energy that can be used for cooling, E_C, is calculated using Equation 2.2. β is a tabulated constant based on what category of building being built. Design Outdoor Temperature Summer (DUT_s) is defined as the average threeday-temperature for a given location, over a 30 year period. [11]

$$E_C = \beta(20 - DUT_s) \tag{2.2}$$

The highest amount of energy that can be used for lighting, is a tabulated value that depends on the building type. The maximum amount of power per square meter that be used for lighting is a tabulated value based on the type of building. NS 3701 requires that 60 % of the lighting system, in terms of installed power, have to be controlled by a sensor system. Using a sensor system to control the lights, is beneficial as it reduces energy consumption. The system must also have at least one sensor per 30 m^2 or per room. [10]

To qualify as a passive house there are also demands for some of the components in the building. These include U-values for the doors, windows and thermal bridges, how efficient the heat recovery system is, SFP factor for the ventilation and for the air leakage number. SFP is short for specific fan power and is a measure on how the energy needed to move air around the system.

2.1.3 FutureBuilt Energy Definition

A FutureBuilt energy-plus-house is defined as a building that compensates for its energy use throughout the year by producing renewable energy. The specific requirement for a FutureBuilt energy-plus-house is to export 2 kWh/m^2 GIA to the power grid per year [8].

Renewable energy production has to occur locally, either integrated into the building or on the property. The amount of renewable energy exported to the power grid compensates for energy imported in the energy calculations. [8]

2.1.4 Rambøll's Energy Report on Skavanger School

As mentioned in Section 1, Rambøll was tasked with creating a report that would include the specifications and requirements needed for Skavanger School to meet the FutureBuilt standard. Considering that the goal of the FutureBuilt standard is to produce more energy than is being consumed per year, energy efficiency is key. By reducing the overall consumption of energy, the need for local energy generation and energy storage to achieve the FutureBuilt Standard is lowered. This report can be found in Appendix A.

Based on the energy report from Rambøll, Skavanger school outperforms the minimum requirements set by TEK17. Both the requirements stated by TEK17 and the actual calculated values can be found in Table 2.2. This is beneficial seeing as increased energy efficiency is directly linked to how much energy production is needed to attain the FutureBuilt Standard.

Table 2.2: *Requirements from TEK17 compared to the calculated values for Skavanger School. Based on the energy report by Rambøll in Appendix A*

Component	Requirement	Estimated Value
U-value Outer Wall [W/m^2k]	≤ 0.22	0.17
U-value Roof [W/m^2k]	≤ 0.18	0.09
U-value Floor [W/m^2k]	≤ 0.18	0.08
U-value Window and Door [W/m^2k]	≤ 1.2	0.63
Air Leakage [h^{-1}]	≤ 1.5	0.30

Similarly, based on the energy report found in Appendix A, Skavanger school outperforms the requirements set by NS 3701. Considering that requirements from NS 3701 change based on the annual mean temperature and type of building. Both the requirements and the estimated values had to be calculated for this specific project. As seen in Table 2.3 and 2.4, Skavanger School is set to perform better than the requirements set by NS 3701. A consequence of this is an increased energy efficiency which allows Skavanger School to reach the FutureBuilt Standard with less energy production. The school is also set to fulfil the requirements in regards to the control system for the lighting.

Table 2.3: *The calculated values for the energy needed for heating, cooling and lighting compared to the requirements, found in NS 3701, for Skavanger School. This is in addition to the U-values linked to infiltration and transmission losses. The values are based on the energy report by Rambøll which is found in Appendix A*

Description	Requirement	Estimated Value
U-values for Transmission and Infiltration Losses [W/m^{2}k]	≤ 0.4	0.3
Maximum Energy for Heating [kWh/m^2]	25.7	23
Maximum Energy for Cooling [kWh/m^2]	5.4	3.5
Maximum Energy for Lighting [W/m^2]	4.5	4.5

Table 2.4: *Requirements and estimated values for components, ventilation, lighting and air leakage, from NS 3701, for Skavanger School. Based on the energy report from Rambøll in Appendix A*

Description	Requirement	Estimated Value
U-value for Windows and Doors [W/m^{2}K]	≤ 0.80	0.63
Normalised Thermal Bridge Value [W/m^{2}K]	≤ 0.03	0.02
Average Efficiency Heat Pump [%]	≥ 80	85
SFP Ventilation [kWs/m^3]	≤ 1.5	1.22
Air Leakage [h^{-1}]	≤ 0.60	0.30

These specifications impact the amount of energy the school consumes and at what time this happens. Figure 2.2 displays the daily total energy demand for Skavanger school over a year. The load profile for Skavanger School was calculated using SIMIEN, a software used for estimating the energy usage of buildings, based on the data from Rambøll's energy report in Appendix A. All of the energy demand of Skavanger School used in this thesis is electrical, as both room and water heating stems from heat pumps and electrical heating systems.

During the weekends, there is close to no activity at the school, and thus the energy demand is close to zero. From July to the middle of August, which is the summer holiday in Norway, the energy consumption of the school drops to a very low level. The outside temperature does have an effect on the energy demand of Skavanger School. During the colder parts of the year, from November to March, the energy usage is considerably higher than during May. Similarly, during the warmest part of the year the need for cooling causes an increase in energy demand. This can be seen during the end of June and the middle of August.

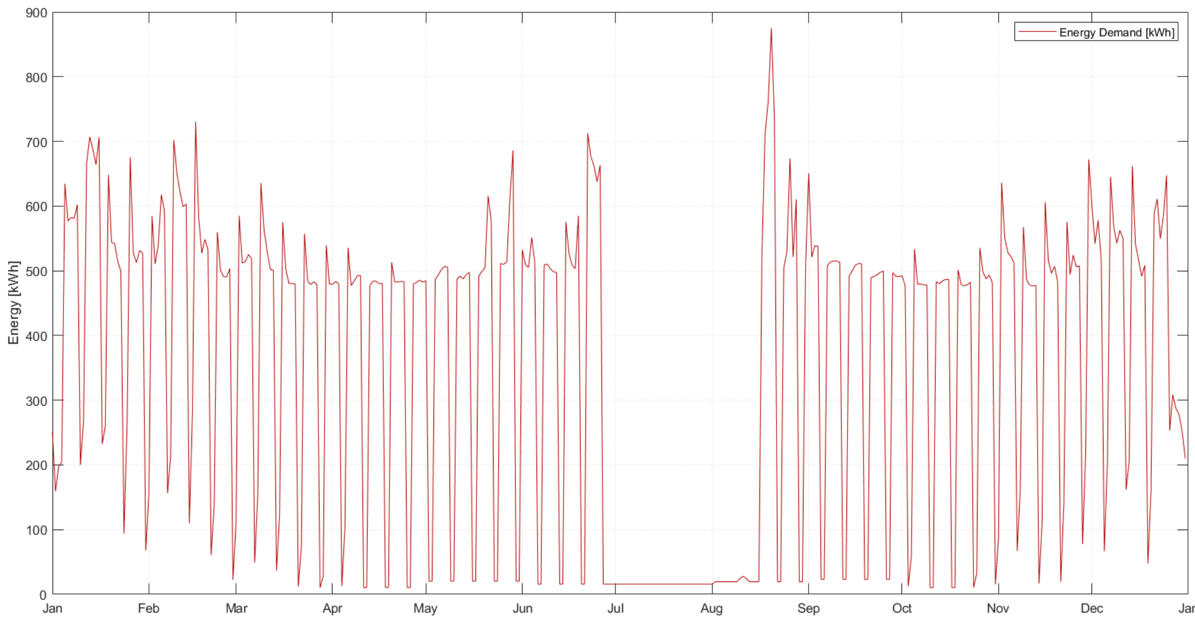

Figure 2.2: *Daily energy demand for Skavanger School over a year.*

Based on Appendix A, the total GIA of the school is 3 301 m^2. Total electricity demand over a year is estimated to be 127 664 kWh. To achieve the FutureBuilt requirement of 2 kWh/m2 surplus energy production, the total energy produced needs to be 134 266 kWh.

2.2 Solar Photovoltaic

This Section will introduce useful and relevant theory about solar PV technology and the data for the two cases with different solar PV areas for Skavanger School.

2.2.1 General Information

The purpose of solar PV is to convert sunlight/solar radiation into electricity. Silicon is the most common material used as semi conductors. The silicon is cut to thin layers called wafers. When the wafers are cut, they are either injected with phosphorus atoms to make a surplus of electrons and thus becoming negatively charged (N-Type). Or injected with boron to make an electron deficit which gives the wafer a positive charge (P-Type). The next step in the process is to connect the N-Type and P-Type wafers as shown in Figure 2.3. [12]

When the two wafers are connected, a depletion zone is formed represented by the area with a dark red colour. It is formed due to the free electrons in the N-Type wafer (in blue) filling the electron holes in the P-Type wafer (in red) in the contact area. The depletion zone makes a separation between the electrons and the electron holes and creates an electric potential because of the wafers' difference in charge. [12]

The separation makes it impossible for the electrons to move to the P-Type wafer without going through the electric circuit. A wider depletion zone closer to the surface makes a higher electric potential. Notice that the P-Type is wider to make the Depletion Zone wider, which also increases the electric potential. When photons hits the solar cell, the electrons moves out of the free electron holes and the electrons are forced into the electric circuit, which starts at the front electrical contact and ends at the back electrical contact. From there the electrons moves up to the electron hole in the depletion zone where it all is repeated. A solar PV panel consists of several solar PV cells of approximately 100 cm^2 and are connected in series and parallel to achieve the right current and voltage. [12]

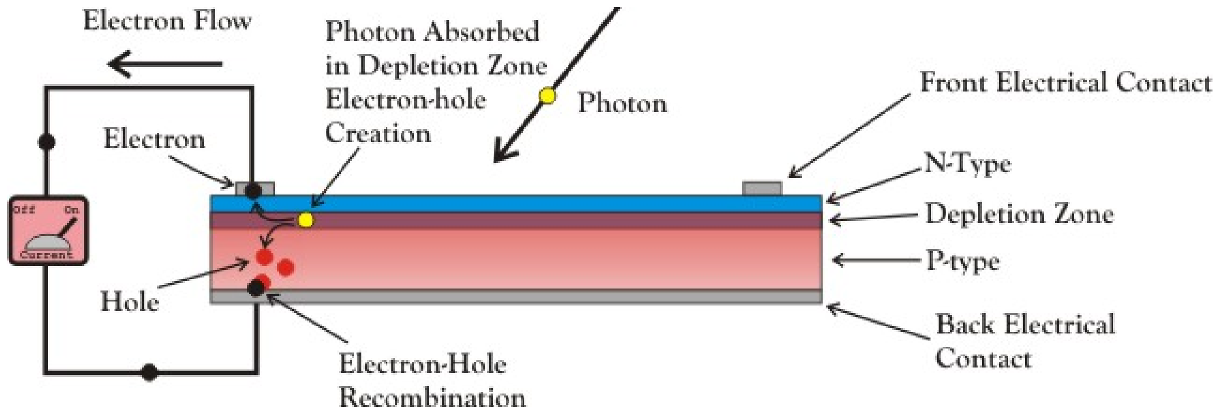

Figure 2.3: *Visualisation of electrical energy being generated in a solar PV cell with the most crucial components being labelled. [13]*

Solar PV has experienced a great growth over the past thirty years. The price for silicon has decreased and more efficient technologies and methods have been developed. Globally, there has been an annual growth of 35 % of the installed capacity since 1990. There has also been a significant growth in the Norwegian solar PV market. In 2018, there was an increase of installed capacity of 29 % from 2017 and 52 % from 2016. [14]

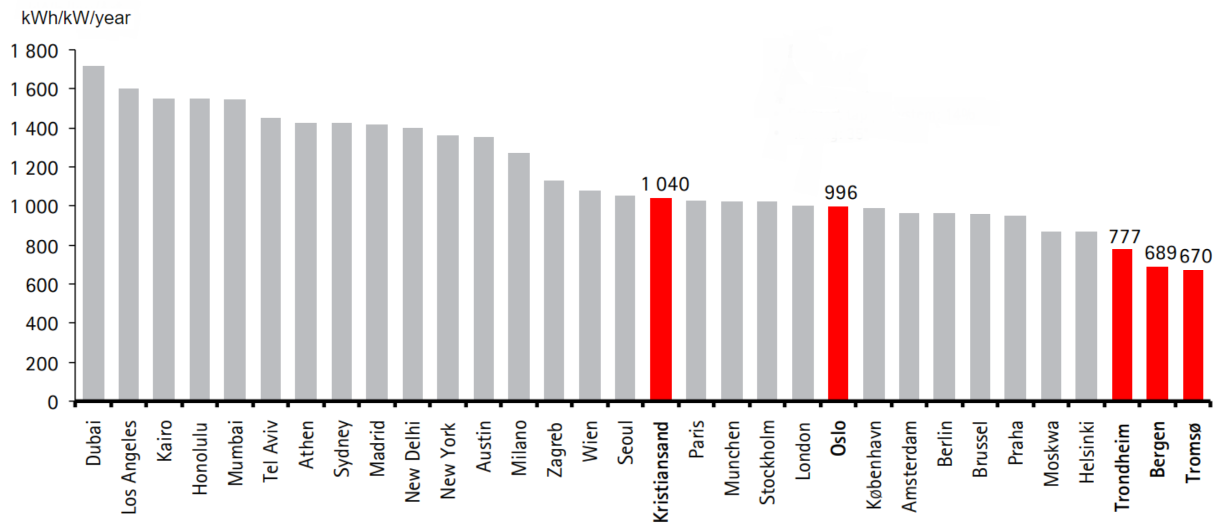

Figure 2.4: *Solar conditions at different geographical locations [15]. Norwegian cities are marked in red. The graph is translated to English.*

Solar conditions are optimal near the equator, and decreases closer to the poles. As a result of this, the conditions for solar PV in Norway are not optimal. However, the conditions in the southern part of Norway are similar to the conditions in many parts of Germany where solar PV comprises a greater percentage of the total energy production. Figure 2.4 shows kWh per kW per year in different locations. The conditions of Kristiansand and Oslo are especially competitive for solar power production [15]. The assumptions for this figure are a 1 kW system with 14 % loss and a 35 °slope. System loss is defined as the losses which causes the electrical power produced by the solar PV panels to lower than the electrical power delivered to the grid. [16–18]

Solar PV plays a crucial role in ZEBs as a part of the energy systems to fulfil different energy requirements, such as FutureBuilt. The Norwegian Water Resources and Energy Directorate (NVE) predicts an electricity production from solar PV of between 4 TWh and 10 TWh by 2040 [5]. Figure 2.5 shows the expected increase in produced solar power from different buildings constructed in separate time periods. The increase of production is small from 2018 to 2019, but is expected to increase steadily at approximately 0.4 TWh per year from 2021 to 2030. The total production from solar power in Norway is estimated to be 4.75 TWh per year in 2030, which is 3.1 % of the total electricity demand of 153 TWh per year [19]. Solar PV is often used in a combination with energy storage devices such as batteries. To be less reliant on the power grid, the energy from the sun can be stored at high production periods and used during low production periods.

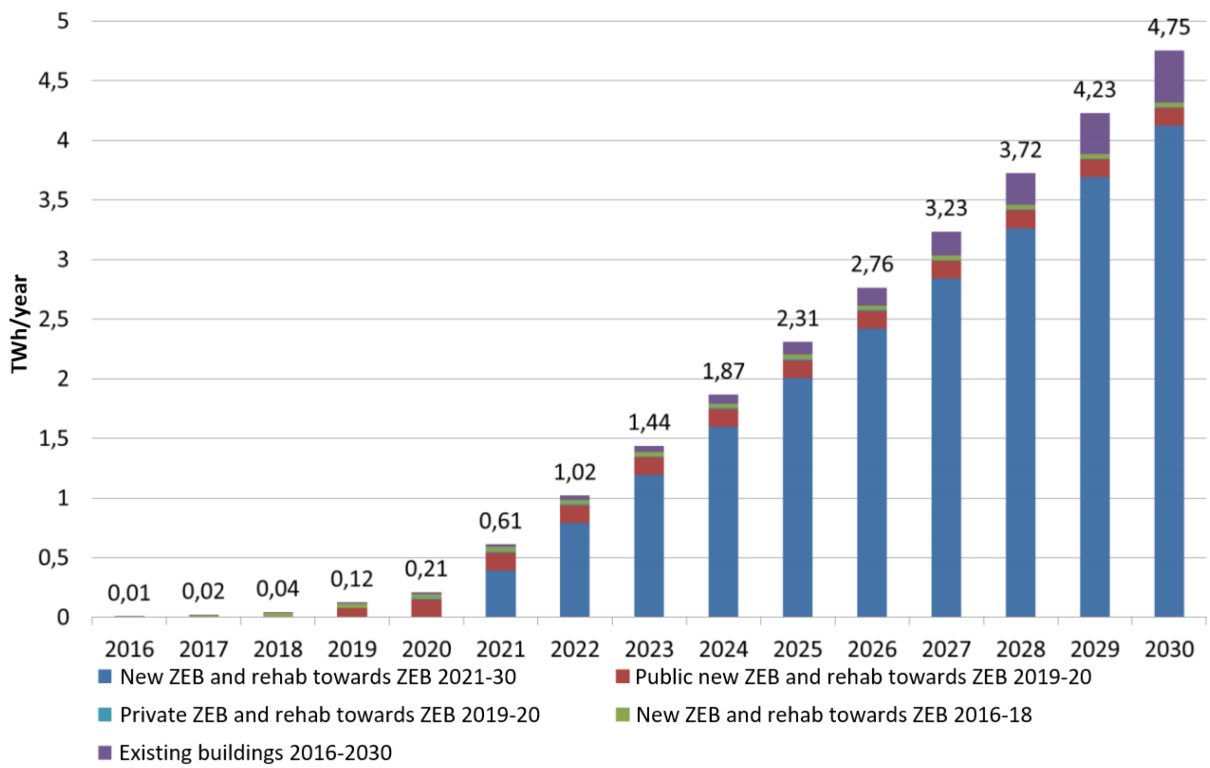

Figure 2.5: *Estimation of solar energy production from buildings in Norway from 2016 to 2030 [16]. The figure is translated to English.*

When constructing solar power plants, certain parameters have to be taken into consideration. Azimuth, slope and the efficiency of the solar PV panel will affect the amount of power produced. Azimuth is used to determine the direction the solar panel is pointing in relation to the cardinal directions. The azimuth is given as rotation in degrees clockwise from the reference direction. The reference direction is often set as south, but may in some cases be set as north or other specific directions. The slope of the solar PV panel is the angle of the panel compared to the horizontal plane. A slope of 0 ° is parallel to the ground, and 90 ° is perpendicular to the ground [18]. By optimising the slope and azimuth, maximum power production can be achieved. In addition to this, these variables may also be used to change the timing of the solar PV production peak to fit the consumption profile [18]. Efficiency is a measurement of how much of the energy from the sun is converted to electric power by the solar cell. This number is dependent on several factors including materials, temperature, technology, wiring and reflection [20]. F

2.2.2 Power Production Profile

The two different cases that are going to be examined are an area of 600 m^2 and an area of 959 m^2. The cost of installation for a solar PV area this size is 9-10 NOK/W and based on the cost range which Sweco use in their projects [11]. For all calculations in this bachelor thesis, the price is assumed to be 10 NOK/W. In Table 2.5, the calculations of the two cases are presented. The maintenance costs associated with solar PV is assumed to be 1.5 % of the investment cost [21] per year. The lifespan of the solar PV panels are assumed to be 25 years [22].

Table 2.5: *Area, installed capacity and price for the two different solar PV areas used in this bachelor [23]*

Case	Area [m^2]	Installed Capacity [kWp]	Price [NOK]
1	959	154	1 540 000
2	600	96	960 000

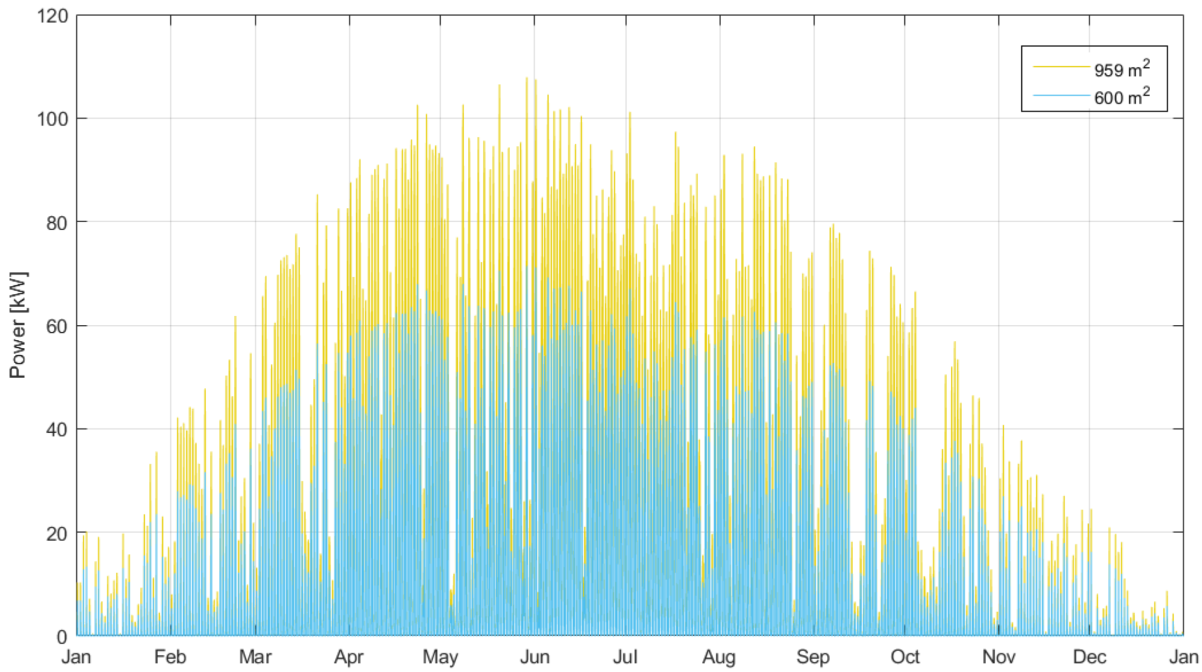

Figure 2.6: *Power production per hour from 600 m^2 (in blue) and 959 m^2 (in yellow) of solar PV at Skavanger School with 14 % system losses, 10 ° slope and 0 ° azimuth.*

Rambøll's energy report in Appendix A concludes with a solar PV area of 959 m^2, which gives an installed capacity of 154 kWp, to fulfil the FutureBuilt requirement of 134 266 kWh. When talking about installed capacity of solar PV, kilowatt peak (kWp) refers to the maximum production from the solar PV panels during standard conditions. This is given as Case 1 in Table 2.5. The report was completed without considering a hydropower plant. Sweco was hired for the task of investigating the possibility of reducing approximately 300 m^2 of solar PV panels and adding a micro hydropower plant. Case 2 is set to 600 m^2 to look at this option.

The tool used for the calculations is Photovoltaic Geographical Information System (PVGIS), and is a software that allows for the most accurate data, without setting up measuring equipment at the location. For the yearly in-plane irradiation data, PVGIS-SARAH is used as solar radiation database which gives 1073.15 kWh/m^2 and 871.82 kWh/kW as the solar conditions at the school [23]. For the calculations, the assumptions are 14 % of system losses in addition to optimised slope and azimuth. These assumptions are used to mirror the assumptions used by Sweco in their report in Appendix C.

The electricity production from solar PV is calculated by Rambøll to be 134 266 kWh over a year. However, from the simulation in PVGIS, the electricity production for 2015 is 139 300 kWh. In Figure 2.6, the distribution of hourly power production for the different cases of solar PV over a year are presented. Most of the production comes from the months May, June and July where the production often is between 100 and 80 kW for 959 m^2 of solar PV and between 60 and 40 kW for 600 m^2 of solar PV. During the months of December and January, there is very little production of solar power.

2.3 Micro Hydropower

Throughout this section, the basic principles of hydropower will be explained. In addition, the relevant information from Sweco's report on possible micro hydropower production at Skavanger School is presented with both costs and production data.

2.3.1 General Information

Hydropower uses the mechanical energy in the water. The water transfers its energy to a turbine connected to a generator that creates electricity. There are several turbine types which operate optimally at different conditions, based primarily on height differences, called head, and volumetric flow rate, often called hydro discharge in this thesis. The turbines are usually placed by a river, or at the end of pipes from a reservoir. The reservoir can be artificial or natural as long as there is a height difference from the reservoir to the turbine [24]. The amount of water available in the reservoir depends on the rate of inflow. Inflow is the sum of all water naturally added to the reservoir, through rivers, streams and precipitation. If more of the inflow is used for electricity production, the level of the reservoir decreases and vice versa.

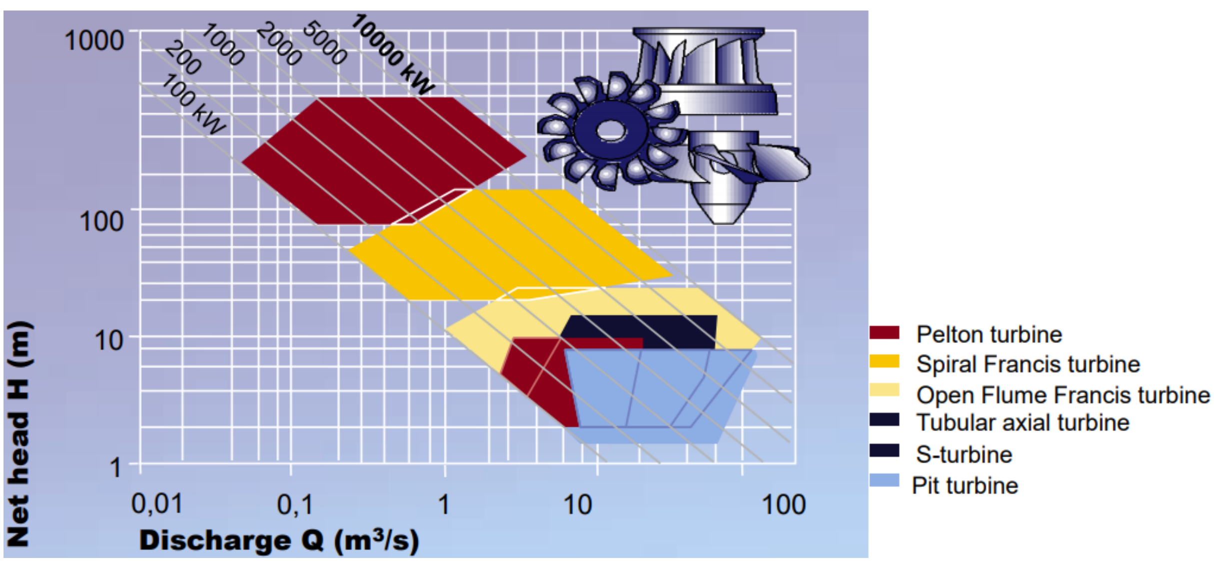

Figure 2.7: *An overview of operating area for different turbine types, based on net head and hydro discharge [25].*

There are several turbines to choose from. The most common turbine when there is a large head and a small volumetric flow rate, is a Pelton turbine is often used as shown as the dark red colour in Figure 2.7 [25]. For the biggest Pelton turbines, the efficiency is between 91 and 93 % [26]. However, when the turbines are smaller, the efficiency will decrease.

Hydropower has the lowest impact on the climate, highest efficiency and longest lifespan of all widespread power production technologies. A typical lifespan of a hydropower plant is 40-60 years [27]. In this bachelor thesis a lifespan of 40 years is assumed. Building a hydropower plant can have negative consequences on the surrounding environment when damming rivers to create reservoirs, but the produced power has very low CO_2 emissions per produced kWh. A hydroelectric power plant is regarded as large when the installed capacity is in the range of 10-20 MW, small in the 1-10 MW range, mini between 100 kW and one MW, and micro if it is below 100 kW [24]. Micro hydropower plants are uncommon because the price of the piping, and other infrastructure necessary can be too costly compared to the generator output. Norway has good prerequisites for the usage of hydropower as there are large and steep mountains, big valleys and high levels of precipitation, resulting in hydroelectricity being the most common source of electric energy [28, 29].

Micro hydropower plants are usually implemented in places with a need for off-grid power production. A micro hydropower plant placed by a stable river can provide close to constant power over a year. This has been an increasingly used source of power in developing countries, and is one of several technologies that can help developing nations skip the use of fossil fuels in the establishment of a stable power grid. However, these power plants can also be used in countries with an existing power system [30]. The almost close to instant response of the hydropower production gives an option to be less dependent on other energy sources, and provides a steady and predictable production. The hydropower plant can be run when there is a demand for energy, and the water can be stored when the demand is low, resulting in a more stable grid [29].

2.3.2 Sweco's Report on Hydropower Possibilities at Skavanger School

For the calculations regarding hydropower, all numbers and figures are based on Sweco's report on the assessment of hydropower production at Skavanger School in Appendix B. The recommended route for the piping of water from the reservoir to the school is fairly long and contains several turns. However, a cooperation with the municipal's water and sewage department regarding a new irrigation system for a sports facility, will make the project more economically feasible. The total cost of installation for the hydropower plant at Skavanger School is presented in Table 2.6.

All prices in Table 2.6, except for piping excavation, are received from a supplier. The price for piping excavation is taken from Sweco's previous projects. Depending on the ground in the area, which has not been been investigated, Sweco assumes that the price will be between 500 - 1000 NOK/m [11]. This thesis assumes the price to be 1000 NOK/m. The price for Power Station, Machine and Electro is a package price. This package includes the turbine case, asynchronous generator, runner, actuator with valve and a control unit with generator, power system protection and a contactor connected towards the energy system. A 5000 NOK/year maintenance expense included for the hydropower plant [11].

The planned installed capacity for the hydropower turbine is 28 kW. With a head of 151 m and a 80 % use of the total inflow, the expected monthly electricity production is shown in Figure 2.8. During the winter months, the production

Table 2.6: *Overview of prices for the hydropower plant with a Pelton turbine. The numbers are modified from Sweco's hydropower report in Appendix B .*

Equipment	Estimates	Price [NOK]
Pipes	1300 m à 180 NOK/m	243 000
Power Station, Machine and Electro	Package Price	175 000
Power Station, Building	Min. 8 m^2	100 000
Cables, Power Station - School	250 m à 250 NOK/m	62 500
Installation Cables	20 h à 1500 NOK/h	30 000
Piping Excavation	1300 m à 1000 NOK/m	1 300 000
Unexpected Costs	15 % of 1 910 300 NOK	286 575
Sum Building Costs		2 197 075

is low due to little inflow. The spring and autumn months has the most production caused by the melting of snow and ice and increased precipitation.

The water reservoir used for the hydropower production is also used by several other parties. To regulate the reservoir in a way that every party is satisfied, the energy system at the school is given two meter of regulation. Two meters of regulation gives approximately 43 000 kWh of energy production from the hydropower plant [11]. The system can use more water in a given month than the inflow, as long as the total water use over a year stays below the total inflow over a year.

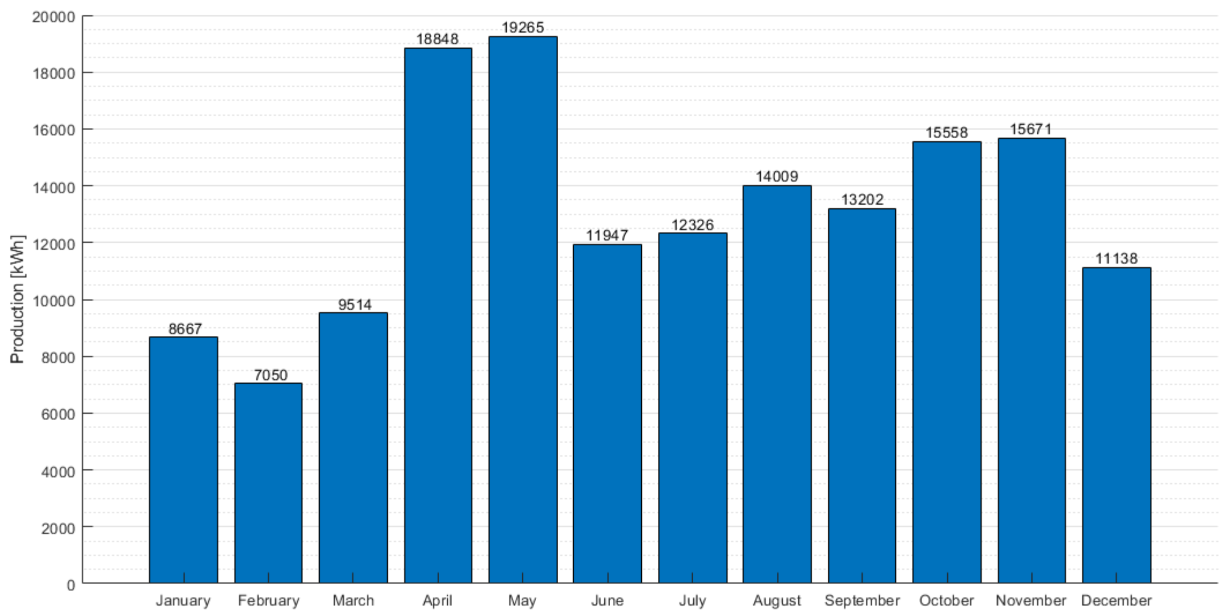

Figure 2.8: *Expected production energy production from a 28 kW generator with 80 % of total inflow over a year. The graph is modified from Sweco's hydropower report in Appendix B.*

2.4 Batteries

As the energy sector transitions into a more complex renewable system, the discrepancy between time of energy production and energy consumption increases. In addition to this, there is an emergence of more local power generation. To ensure a reliable energy supply, energy storage will be an important component when planning future energy systems. [5, 31]

2.4.1 General Information

A battery is a form of energy storage where electrical energy is stored as chemical energy. The base of a battery is an electrochemical cell which can be seen in Figure 2.9. The cell consists of a cathode and anode, an electrolyte solution, a semi-permeable barrier and an external circuit. It is the flow of electrons through the external circuit that results in electrical power being generated. At the anode, a reaction with the electrolyte produces a surplus of electrons. Meanwhile a deficit of electrons build up at the cathode. The semi-permeable barrier prevents the electrons from crossing, leaving only the external circuit as a path for the electrons. [32]

Battery capacity is measured is watt hours and represent how much energy that can be retrieved from a fully charged battery during nominal conditions. Over time, the capacity of a battery decreases. This is caused by several factors, which include the number of charge cycles, the frequency of the cycles and operating temperature. Batteries generally preform better at higher temperatures. [33]

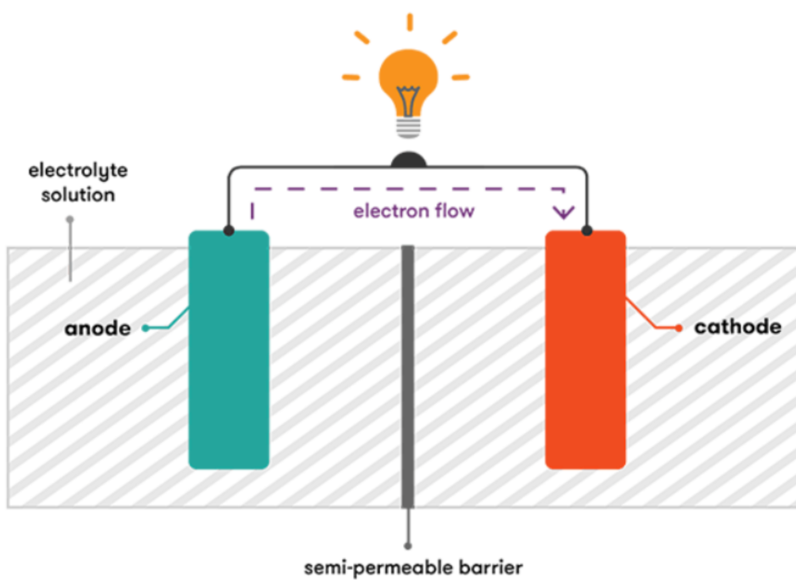

Figure 2.9: *A simplified schematic diagram of a electrochemical cell. [32]*

One of the most widely used battery chemistries today is the lithium ion (Li-ion) battery. These are used in phones, laptops, electrical vehicles, among other devices. In Li-ion batteries both the anode and the cathode can hold Li-ions. When the battery is completely discharged, all the Li-ions are held by the cathode. Similarly, when the battery is fully charged, all the Li-ions are held by the anode [34]. Li-ion battery packs have experienced a big drop in price in the recent years.*Li-ion batteries for mobility and stationary storage applications* from the European Commission, states that Li-ion battery packs have dropped approximately 75 % in price from 2010 to 2017 [35].

Li-ion batteries hold several key characteristics which make them well suited for energy storage. In Table 2.7, the most important characteristics are highlighted and compared to lead-acid and nickel-cadmium chemistries, as these are other battery chemistries used in rechargeable batteries. Energy density is important for mobile applications as it signifies the amount of energy per unit of mass. The number of cycles refers to how many charging cycles a battery can experience before it must be changed due to a loss of capacity. Efficiency is the ratio between the energy received from the battery, compared to the amount of energy used to charge it. [36]

Table 2.7: *Overview of different battery characteristics, for three battery chemistries used in rechargeable batteries. [36].*

Battery type	Energy density [Wh/kg]	Number of cycles	Efficiency [%]
Lead-Acid	20-40	1000-5000	60-90
Nickel-Cadmium	40-60	1000-3000	80
Li-ion	150-250	1000-20000	90-98

For a energy storage system, longevity is an important aspect to consider. The longer the system can be used, the better the economic outlook becomes. There are several factors that impact how long a the system can remain operational. Depth of discharge (DoD) is a measure of how much the battery is discharged compared to the maximum charge it can hold. For example, if a battery is fully discharged, the DoD is at 100 % [36]. How the battery is operated, in terms of what DoD is used, impacts how fast the battery capacity diminishes. For example a Li-ion battery operated at 100 % could do approximately 300 discharge cycles before the battery capacity dropped to 70 %. However, if the DoD is at 60 % the number of cycles doubles to 600 [37]. Another factor which impacts battery longevity is the cell voltage used. For most Li-ion cells, the peak charge voltage is 4.20 V [37]. Each 0.10 reduction in peak charge voltage doubles the amount of discharge cycles the battery can withstand [37].

While manipulating these factors increase the amount of discharge cycles available, it is not without downsides. To increase the amount of cycles, the amount of energy available to use from storage is reduced. Changing the DoD changes how much energy has to be left in the battery at all times. Reducing the peak charge voltage reduces the total amount of energy the battery can store. [37]

2.4.2 Second-Life Batteries at Skavanger School

The capacity of a battery will degrade over time. This essentially decreases the energy density of the battery. A lower energy density is undesirable for mobile applications such as electric vehicles. Generally, batteries used in electric vehicles are retired when they reach 80 % of initial capacity [38]. Batteries that have been retired and put to different use are called second-life batteries. These are suitable for stationary applications, such as a school buildings, cabins and buildings in general.

In this thesis, the total cost of energy storage using second-life Li-ion batteries is set to 2350 NOK/kWh based on prices from the Eco Stor [11]. The planned battery capacity for the school is 150 kWh as mentioned in Appendix C.

The intention for the battery is to supply the energy system with electricity during the peak hours of the day in addition to storing overproduction of solar PV. A reduced battery capacity of 75 kWh will also be researched in this thesis. The two different cases that will be examined are presented in Table 2.8, alongside the cost of each battery. The assumed battery lifetime is 7 years and charging power of 50 kW and discharging power of 100 kW is assumed [11, 38].

Table 2.8: *Overview of the prices for the two battery sizes [11]*

Case	Battery Size [kWh]	Price [NOK]
1	150	352 500
2	75	176 250

Historically, Li-ion battery packs have experienced a big decrease in price. From 2010 to 2017 the battery price fell from approximately 800 €/kWh to 200 €/kWh [35]. In the future, there is a big span in predicted prices for Li-ion battery packs [35]. In this bachelor, a halving of the battery prices is assumed over 20 years, which amounts to a 3.41 % decrease every year. In this bachelor thesis, the battery is changed every seven years, due to degradation [11].

2.5 The Power Grid and the Pricing Structure of Electricity

The power grid is the psychical components that transport energy from the place of production to the place of consumption. The Norwegian electricity grid is divided into three different levels. The transmission grid has the highest voltages levels and connects producers of power to the grid. This grid is also connected with other countries. The regional grid serves to connect the transmission grid to the lowest level of power grid. This level is called the distribution grid and serves to supply the end users with electricity. [39]

Considering electricity is a commodity which is not easily stored, balance between production and use is critical. To ensure this the Norwegian power grid is divided into bidding areas. Tasks regarding the power grid such as operation, maintenance and development are monopolised, while energy production and trade is market-based. Every day, a system price is calculated by Nord Pool, which is a company offering power market and trading services for fifteen countries in Europe. This is a theoretical price that serves as a reference price for the financial power market. Based on the system price and other factors, such as costs associated with running a power plant, producers of power declare how much power they will produce at different price levels. Different entities that require power, such as power suppliers or large industrial consumers, submits a bid reflecting how much power they need at the different price levels. In Norway, there are five different bidding zones. This is caused by a difference in the power situation throughout Norway. Some areas have a power surplus, while other areas have a deficit. These prices change relative to each other depending on the power situation in the respective areas. Figure 2.10 illustrates how the bidding areas are divided for some of countries which are part of the Baltics and Nordics. [40].

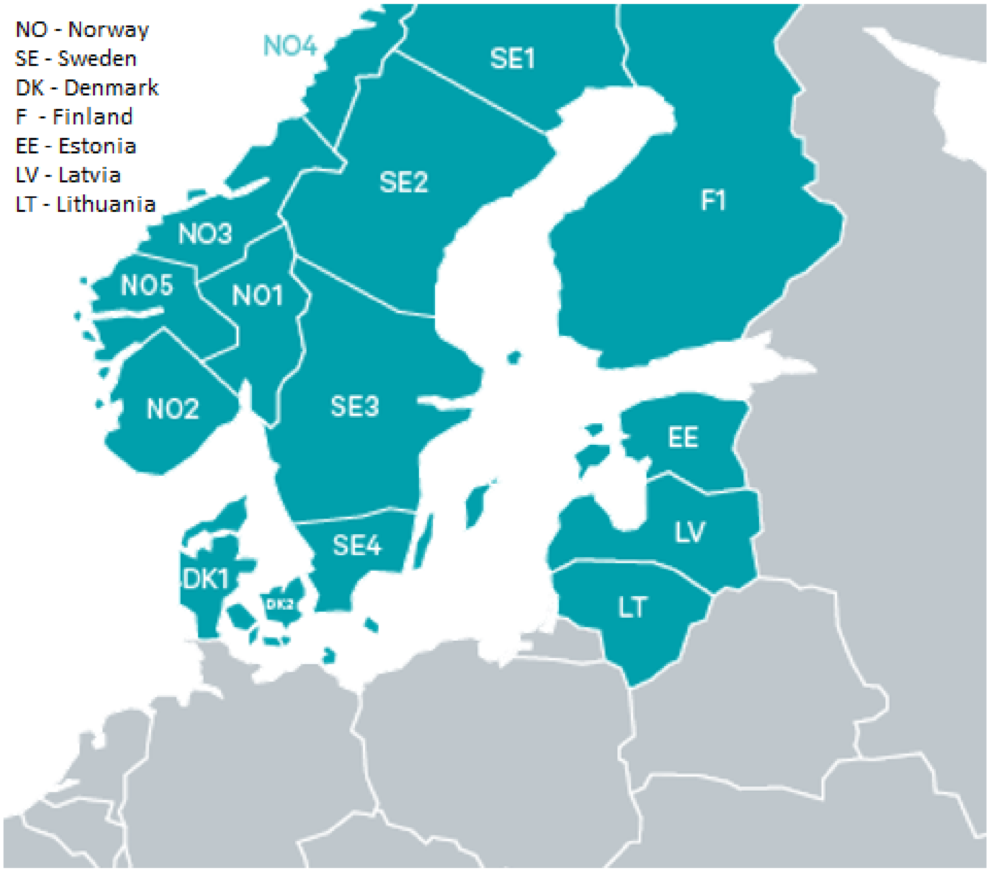

Figure 2.10: *Illustration of bidding areas in the Nordic and Baltic countries, except for Iceland. The different countries are split into different bidding areas to reflect the difference in the power situation throughout a country. This causes the spot price to differ, based on the bidding area. Norway is divided into five bidding areas, while the smaller countries such as Estonia only has one.*

Small scale end users, such as homes or small businesses, buy their power from power suppliers. These generally choose from two types of power contracts. A fixed-price contract and a spot price contract. A fixed price contract has an electricity price that remains the same over a certain period of time, usually a year. A spot price contract entails that the electricity price follows the Nord Pool determined market price. In addition to paying for the amount of energy used, end-users must also pay grid rent to the local grid operator. Grid rent fee is split into two parts, an energy tariff and a power tariff. The energy tariff is composed of two parts, a variable part and a fixed part, and is based on the total amount of energy used throughout the month. The power tariff is calculated based upon the hour of the month where the most power is used. [40–42]

In Kongsberg municipality, the local grid operator is called Glitre Energi Nett AS [43]. Their pricing structure will be used to calculate the total price of electricity in this bachelor thesis. The rates for the variable part of the energy tariff and the power tariff, change based on the time of year and day of the week. The pricing structure is presented in Table 2.9 and considers the winter months to be from October to March while the summer months are from April to September. 07:00 - 20:00 is considered to be daytime while 20:01 - 06:59 is nighttime. Monday to Friday count as working days while Saturday and Sunday is considered to be the weekend. [44]

Table 2.9: *The pricing structure used by Glitre Energi Nett AS. The table is modified from [44].*

Tariff/Tax	Cost
Fixed Grid Rent [NOK/year]	5800
Power Tariff $<$ 300 kW Winter [NOK/kW/month]	87
Power Tariff $>$ 300 kW Winter [NOK/kW/month]	67
Energy Tariff Winter Day [NOK/kWh]	0.075
Energy Tariff Winter Night/Weekend [NOK/kWh]	0.069
Power Tariff $<$ 300 kW Summer [NOK/kW/month]	12
Power Tariff $>$ 300 kW Summer [NOK/kW/month]	9
Energy Tariff Summer [NOK/kWh]	0.059
Consumption Tax [NOK/kWh]	0.1613

Buildings with local energy production can export surplus energy to the grid. End-users that both consume and produce energy are known as prosumers, and they gain income both from the grid operator and the power supplier. The grid operator pays a small amount for energy put back in to the grid, as this reduces losses in the grid caused by the transportation of energy. Glitre Energi Nett AS uses the rates listed in Table 2.10 for energy prosumers sell back to the grid. The rates for exporting energy varies based on what time of year and time of day it is. In Norway, a prosumer cannot export 100 kW or higher at any given moment. A prosumer wanting to export more than 100 kW of power will need to get a licence from NVE [45].

Table 2.10: *The prices used by Glitre Energi Nett AS to purchase energy from prosumers [44].*

Period	Price [NOK/kWh]
Winter Day	0.016
Winter Night/Weekend	0.015
Summer	0.015

The revenue earned by selling energy to the grid for prosumers depend on the chosen power supplier. Different power suppliers offer different terms and conditions. In this thesis the spot price for electricity will primarily be based on monthly Nord Pool data from 2008. Monthly spot prices from 2010 and 2015 will also be used for comparison. The price data is listed in Table 2.11. How the spot price varies from month to month does not follow the same pattern for the three different years. For 2015 the spot price was highest during the winter, meanwhile in 2008 the highest spot price was in the summer.

Table 2.11: *Monthly spot price for electricity in 2008, 2010 and 2015 according to Nord Pool [46].*

Month	2015 [NOK/kWh]	2008 [NOK/kWh]	2010 [NOK/kWh]
January	0.257	0.360	0.411
February	0.246	0.295	0.643
March	0.214	0.212	0.484
April	0.212	0.217	0.385
May	0.181	0.100	0.355
June	0.119	0.200	0.361
July	0.080	0.301	0.366
August	0.101	0.389	0.340
September	0.121	0.512	0.385
October	0.199	0.462	0.396
November	0.231	0.434	0.449
Desember	0.168	0.403	0.656

Based on NVE's report on the long term development in the Norwegian power market, there is a high uncertainty when predicting the spot price development [5]. As seen in Figure 2.11, by 2040 the average spot price could be as high as 51 øre/kWh or as low as 28 øre/kWh. To account for this uncertainty, a yearly increase will be assumed in this thesis. This increase will ensure that the yearly average spot price will reach approximately 43 øre/kWh after 25 years, which is the base scenario for NVE's report and can be seen in Figure 2.11. The yearly increase used will change based which year the spot prices are from. For 2008 it will be a 0.8 % increase, 0 % for 2010 and 3.5 % for 2015.

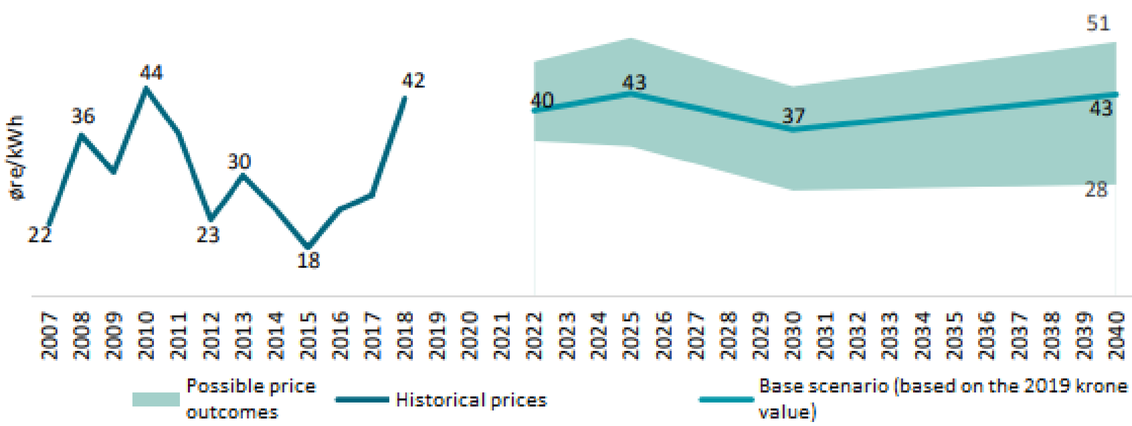

Figure 2.11: *The historical average spot price compared to the predicted spot price in the future [5]. The figure is translated.*

The total cost of electricity can be calculated using Equation 2.3.

$$C_{tot} = \sum_{m}^{Y} [c_e \cdot E_{im}(m) + c_{g,v} \cdot E_{im}(m) + c_{tax} \cdot E_{im}(m) - c_{rate} \cdot E_{ex}(m)] + \sum_{m}^{Y} [c_p \cdot P_p(m)] + c_{g,f} \tag{2.3}$$

- C_{tot}: The total electricity bill over the calculation period excluding value added tax (VAT).
- c_e: Rate charged by the power supplier per kWh used. There are different monthly values.
- $c_{g,v}$: Energy tariff charged by the grid operator per kWh used. The rate charged changes based on the time of the day and which season it is.
- $c_{g,f}$: Fixed grid rent charged by the grid operator.
- c_{tax}: Consumption tax levied by the Norwegian state per kWh used.
- c_p: Power tariff charged by the grid operator. This changes based on the time of the year.
- c_{rate}: Rate per kWh exported to the grid. This changes based on the time of the year and the time of the day.
- E_{im}(m): The sum of imported energy from the grid per month.
- E_{ex}(m): The sum of exported energy to the grid per month.
- P_p(m): The highest value of power imported over an hour. This is calculated per month.
- Y is the last month of the calculation period and m represents months.

After the total electricity bill is calculated for the given calculation period, VAT has to be added. In Norway, the VAT is 25 % [47] and this leads to the C_{tot} for the calculation period being multiplied by a factor of 1.25.

2.6 Self Sufficiency

Moving towards 2040, a larger part of the energy production is going to come from renewable sources. As mentioned in the *Power market analysis towards 2040* report produced by NVE, the Nordic countries are moving towards complete carbon neutrality in their power systems by 2040 [5]. In 2014, the European Union (EU) committed to cut 40 % of their greenhouse gas emissions by 2030, compared to 1990 levels [48]. These countries are highly dependant on renewable energy to accomplish this goal. Another factor which will change the European power market, is the increase in exchange capacity between countries. The amount of power which can be transmitted between countries is expected to double by 2030 [48].

Moving from an energy mix dominated by thermal energy, where energy can be produced at a fixed and predictable rate, to an energy mix where renewables are the main source of energy will affect the power trading market. Renewable energy sources generally produce energy on a intermittent basis, which could lead to a more unpredictable energy generation. Increased energy transmission between areas with a surplus and areas with a deficit of energy could be used to alleviate this problem. For this to happen, the power grid infrastructure has to be improved. The effect of this, alongside other factors mentioned in the report, could result in a general increase in the price of electricity. [5,48].

To combat this price change, end-users such as households or schools could strive towards partial or complete self sufficiency from the grid. Producing local power, trough for example solar power, and increasing energy efficiency is necessary to accomplish this. In periods of increased power cost, being able to cover the power demand without the need of the grid could be economically beneficial, in addition to increasing the energy security for the user.

The self sufficiency,S_s, is expressed as a percentage of how many hours in a year an energy system produces enough energy to cover its own usage, as represented with Equation 2.4. E_p(t) is the energy produced in the given hour plus the energy used from the batteries. E_u(t) is the energy consumed in the same hour. If the production of power is greater than the consumption, the excess amount of energy will be stored in the batteries or exported to the grid. If E_p(t) is greater than E_u(t), E_p(t) will be set to be equal to E_u(t). This is to calculate how much of the produced energy that is actually consumed by the energy system, in contrast to only looking at the total energy production compared to the total energy consumption.

$$S_s = \sum_{t=0}^{8760} \left(\frac{E_p(t)}{E_u(t)}\right) \cdot \frac{1}{8760} \cdot 100\% \tag{2.4}$$

$$E_p(t): \begin{Bmatrix} E_p(t) > E_u(t) \rightarrow E_p(t) = E_u(t) \\ E_p(t) < E_u(t) \rightarrow E_p(t) = E_p(t) \end{Bmatrix}$$

2.7 Economic Incentives

In Norway, Enova is an organisation working towards lowering societal emissions and investing in the energy system of the future. Enova is owned by the Norwegian Ministry of Climate and Energy and operate by providing economic assistance to projects in line with the organisation's goals. [49]

Projects bringing innovation to the construction and building sector, can apply for economic support to reduce investment costs. Enova can provide 30-60 % of the additional cost linked to the innovation, compared to using the standard solution. Concerning the energy system at Skavanger school, the entire energy system can be regarded as an additional cost. The standard solution for supplying the school with energy would be to import all the energy from the grid. [50] In this bachelor thesis a 40 % coverage of investment costs from Enova is used in the economic calculations.

3 Methodology

In this section of the bachelor thesis, the methodology used to simulate the energy system is explained. Based on the thesis statement quantifying lifetime costs and self sufficiency for the different scenarios, while looking at their ability to fulfil the FutureBuilt requirement is the main focus areas.

To investigate the energy system at Skavanger School, different scenarios for the energy system were created. In these scenarios, the energy system is changed by varying the installed capacity of the components. To simulate the scenarios a simulation model was created using MATLAB®. In the model, data from different sources, such as solar irradiance or electricity prices, are processed. The data is run trough the simulation, where the different parts of the energy system are emulated. The simulation model is based on assumptions and simplifications meant to provide a reasonable estimate to how the given system could perform. Both the scenarios and the model are further explained in this section.

3.1 Scenarios

To get a proper understanding of how the system will perform, a choice was made to look at several scenarios. The scenarios contain different configurations of the energy system, in terms of solar PV area and battery capacity. All the scenarios in Table 3.1 includes the 28 kW hydropower plant except for the Original scenario.

Table 3.1: *The solar PV area and battery capacity used in the different scenarios. All the scenarios, except scenario Original, includes a 28 kW hydropower plant.*

Scenario	Solar PV Area [m^2]	Battery Capacity [kWh]
Original	959	0
Hydro	0	0
Hydro-A	0	150
1-A	959	150
1-B	959	75
2-A	600	150
2-B	600	75

The reason to include both areas of solar PV was to use values from the original report made by Rambøll, where they concluded with 959 m^2 of solar PV, and Sweco's hydropower report, where they wanted to cut approximately 300 m^2 of solar PV from Rambølls report. The battery capacity planned to be installed at the school is 150 kWh, but to see if it could be more favourable with a smaller battery, a 75 kWh battery is also considered.

3.2 Simulation Model

MATLAB® was used for the simulation to produce comparable results of production from the different scenarios, as well as looking at the economics of these with low, medium and high spot prices. Because of large variations in temperatures for different years and the continued increase of temperatures globally, the choice of looking at values for one sample year, 2015, was made. The simulation will use the following values for the calculations:

- Hourly energy demand
- Hourly power from solar PV panels
- Hourly power from hydropower
- Battery size
- Pricing structure from grid operator and power supplier
- Spot price for energy
- Investment and maintenance costs for the solar PV panels
- Investment and maintenance costs for the hydropower plant
- Investment and maintenance costs for the the batteries

The hourly energy demand of the school was extracted from the Sweco's report on thermochemical storage in Appendix C. This data shows the total hourly demand for electricity. It is not known which year the demand calculations are based on. The choice of year will have an impact on the relationship between solar radiation, temperature, electricity prices and energy demand. It is however assumed that the demand is based on an average of historical data, and can therefore be assumed as representative, but with some deviation compared to real life [11]. Hourly data for solar irradiance and production were extracted from PVGIS as mentioned in Section 2.2.2, for the year 2015.

For the hydropower, the data was based on the report from Sweco's hydropower report, found in Appendix B. The values used in the report are based solely on inflow. An average inflow value for each hour is calculated based on the monthly inflow values, and is the value for how much the hydropower plant can produce without affecting the level of water in the reservoir. Both the inflow values and the amount of water in the reservoir are given in kWh of potential production from the hydropower plant. It is possible to regulate the reservoir by two meters, and therefore the hydropower plant is able to produce more than the inflow over a week or month as long as it does not exceed the total inflow over a year. The starting value of the reservoir is 43 000 kWh from the two meters of regulation allowed, as mentioned in Section 2.3.2. Section 3.2.1 explains the simulation in further detail.

The choices of a 150 kWh battery was based on the Sweco report on thermochemical storage in Appendix C. In addition to this, scenarios with a 75 kWh battery was added to investigate the effect of a decrease in the battery capacity. The goal is to see how the battery capacity affects the self sufficiency and the total lifetime cost for the energy system.

A Glitre Energi Nett AS is the grid operator for Skavanger School. Their pricing structure is therefore used in the simulation model and is presented in Section 2.5.

Monthly spot prices for energy is based upon data from Nord Pool [46]. The electricity bill is calculated with spot prices for 2015, 2008 and 2010, which represents a low, medium and high spot price. The average spot price was 0.18 NOk/kWh in 2015, 0.36 NOK/kWh in 2008 and 0.44 NOK/kWh. These were used to illustrate how differing spot prices impact the total lifetime costs over 25 years.

3.2.1 Model Specifications and Assumptions

The simulation is split into three parts. The first part looks at the demand compared to solar production and adjusting the hydropower production to fill in the remaining energy demand, which is illustrated in Figure 3.1. The second part looks at the battery charge, and either adjusts the hydropower production to charge the battery, or uses the stored energy if required. The last part calculates the electricity bill and lifetime cost for each scenario. All scenarios are based on the same script, but with slight modifications in starting parameters to fit each scenario. The two flowcharts are in some cases dependent on each other and are therefore in the simulation included inside the same for-loop, but are for illustration purposes and ease of reading split into two flow charts.

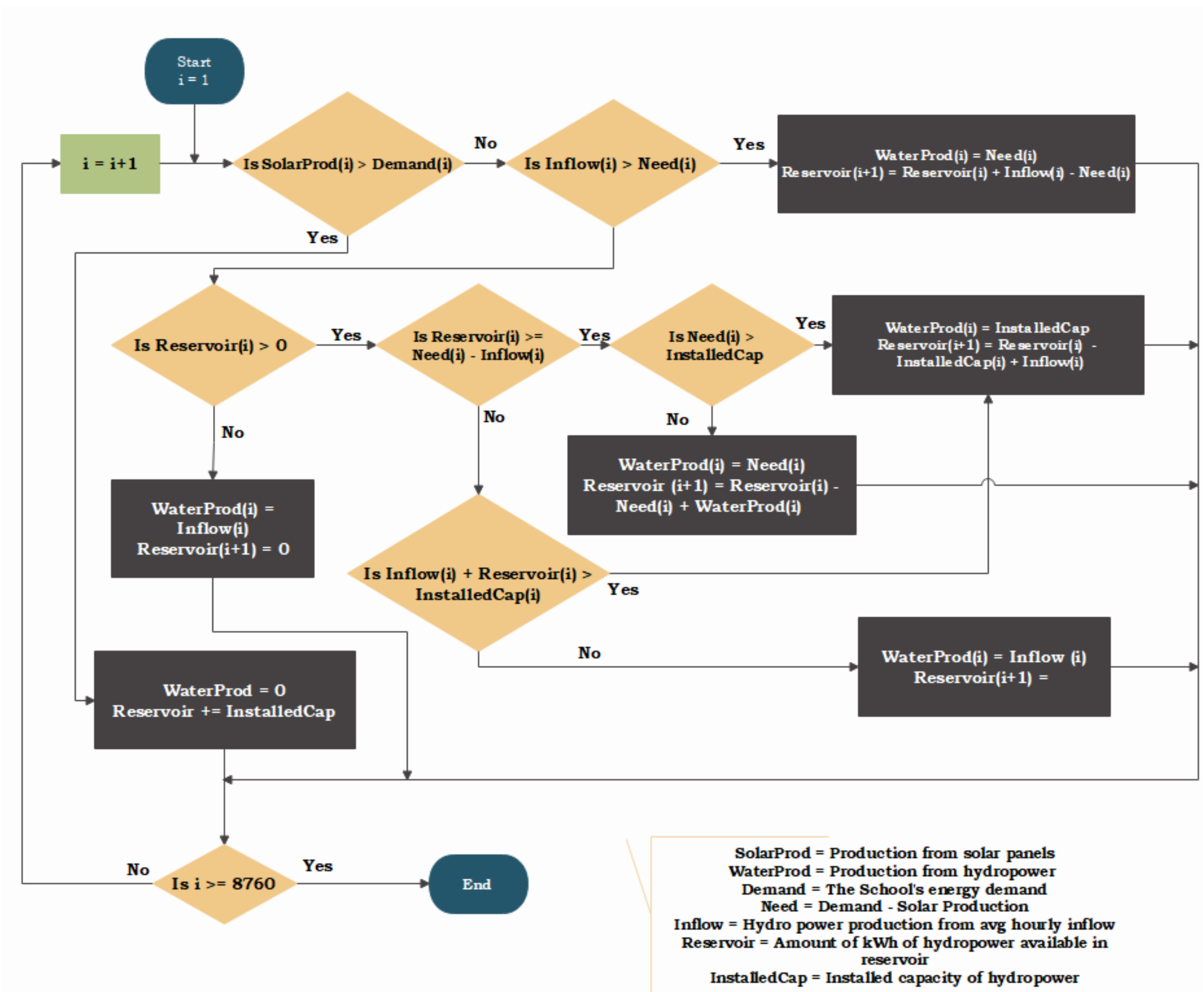

Figure 3.1: *Flowchart of the simulation code that regulates the hydropower production based on demand, solar power production and amount of water in the reservoir. Yellow boxes are decisions, grey and green boxes are processes.*

Figure 3.1 shows a flowchart illustrating how the simulation decides the hydropower production for each hour. The system is run as a loop for every hour in a year, with the starting value of the reservoir at 43 000 kWh. The model checks if there is a *need* for more energy than the solar PV panels can provide. In this section concerning the simulation model, the need is used as a measure of the energy demand, minus the solar power production. If the average hourly inflow at that time is sufficient to cover the need, the system will match the production to the need without drawing additional water from the reservoir.

If the need is not met by the average inflow, the system can use extra water from the reservoir, as long as there is water available. If that is the case, the simulation checks how much water that is available and compares it to the need minus the inflow. If the reservoir has more water in the reservoir than the need for that specific hour, the system will run the water at either the same level as the need, or at maximum capacity if the need exceeds the installed capacity. In the case that the reservoir has a small amount of water, but not enough to satisfy the need, the reservoir will empty and set the water production to equal the available amount in the reservoir plus the inflow. When a value for the production is set, the simulation makes sure the reservoir values for the start of the next hour are updated, and checks if there are more hours left in the year before increasing the index by one to simulate the next hour. This continues until the last hour of the year.

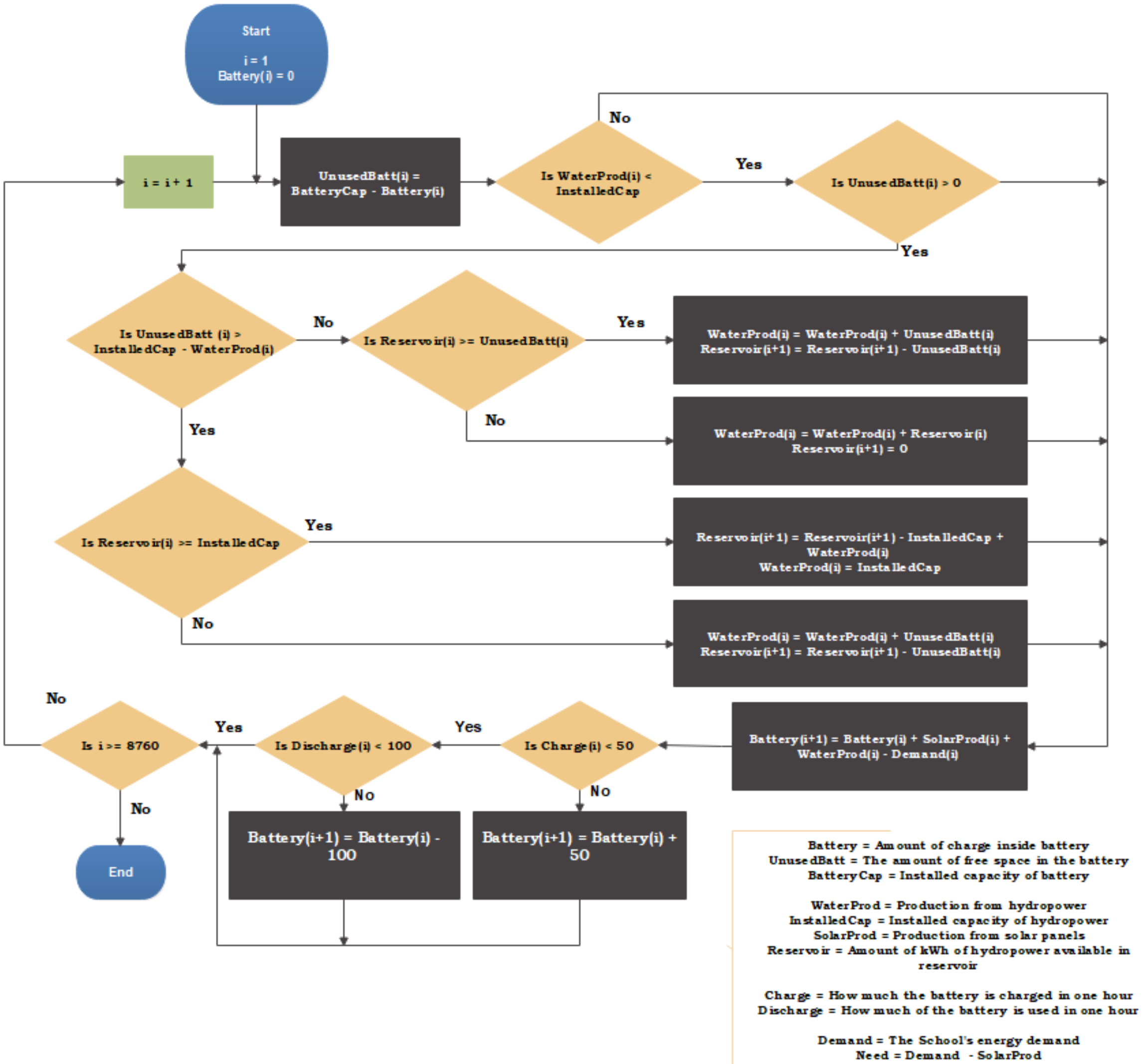

Figure 3.2: *Flowchart illustrating the part of the simulation deciding if the hydropower production is adjusted to charge the battery, or if energy is required from the battery. Yellow boxes are decisions, grey and green boxes are processes.*

The battery calculation is done in a similar fashion to the water production and is shown in the flow chart in Figure 3.2. The the simulation first checks the battery charge and what capacity the hydropower plant is running on. This is because the battery only can be charged if the hydropower plant is not already running at maximum capacity, and if the battery is not full. The simulation will then check if the available capacity in the battery is larger than the difference between the water production and the installed hydropower capacity. If this is true, the simulation checks if there is enough water in the reservoir. If this is the case, the simulation increases the water production to maximum capacity and if not, it only charges the battery with the available amount in the reservoir. If the free space in the battery is less than the potential increase in hydropower production, the hydropower will only be adjusted up to the amount required to fill up the battery.

After each of the previous loops, the start value of the battery for the next hour is set. The system will then check if the battery has charged or discharged more than the specifications of the battery, and if so the battery value is adjusted to stay within the parameters, which are 50 kW charge and 100 kW discharge. If a high hydropower production has led to overcharging the battery, the system will correct the battery and hydropower values to stay within the limits of the battery. The loop then increases the index value and runs again for every hour until the last hour of the year. This part of the simulation is included in the same for-loop as Figure 3.1. Because of this, the hydropower production and reservoir values can be overridden to account for the battery charging and discharging without affecting the results.

The simulation provides hourly, daily, monthly and yearly data for the following values in Table 3.2:

Table 3.2: *Energy specific values from the simulation model.*

Output	**Unit**
Imported Energy from the Grid	kWh
Exported Energy to the Grid	kWh
Energy from Hydropower and Solar PV	kWh
Total Energy Production	kWh
Battery Charge	kWh
Total Energy Used from the Battery	kWh
Amount of Water in the Reservoir	kWh
Energy Consumption of the School	kWh
Self Sufficiency with and Without the Battery	%

To calculate the economical part of the simulation, the results from the production part of the simulation are used. The simulation splits the hourly data into summer and winter, in addition to day, night and weekends. By using the results from earlier parts of the simulation along with Equation 2.3 and Table 2.11, the total lifetime cost and electricity bill are calculated. The following values in Table 3.3 are output values in this part of the simulation, and each have hourly, daily, monthly and yearly values.

As the spot price varies from year to year, all the economic calculations have been done with three different spot prices. This was done to see how the results from the different scenarios changes with varying spot prices. The chosen spot price values were 0.18 NOK/kWh for a low price year (2015), 0.36 NOK/kWh for a medium price year (2008) and 0.44 NOK/kWh for a high price year (2010). The yearly increase in spot price was adjusted for each of the low, medium and high prices. This was done to ensure the spot price ended up at 0.43 NOK/kWh after 25 years, as stated in NVE's market analysis [5]. For all the calculations of future years, an inflation value of 2% is added to each element of the economic simulation.

Table 3.3: *Economic output values from the simulation.*

Output	**Unit**
Cost of Import of Power from the Grid	NOK
Revenue from Export of Power to the Grid	NOK
Power Tariff	NOK/kW
Energy Tariff	NOK/kWh
Consumption Tax	NOK
Total Lifetime Cost	NOK

All the assumptions used in the thesis, are presented in Table 3.4. To increase readability the assumptions are grouped based on what area of the bachelor thesis they affect. Some assumptions are taken from reports or suppliers and relatively certain. Other assumptions, such as the prices for solar PV and general maintenance, are based on Sweco's experience from other projects. The most speculative assumptions are based on reports and personal communication with the supervisors.

Table 3.4: *Assumptions used in the simulation of the energy system.*

Category	Assumptions
Solar PV	- The solar irradiance data from 2015. [23] - 14 % system loss and optimised slope and azimuth, using database PVGIS-SARAH which is standard in PVGIS and used by Sweco in Appendix C. - Lifetime of 25 years. [22] - The same energy production each year. [11]
Hydropower	- The production of hydropower is based solely on inflow to the reservoir, presented as scenario 3 in Sweco's hydropower report. Which is found in Appendix B. - Assumed use of Pelton turbine from Sweco's hydropower report in Appendix B. - Lifetime of 40 years. [25] - The same energy production each year. [11]
Battery	- The battery in the simulation has a round-trip efficiency of 100 %. [11] - The battery operates at a depth of discharge of 100 %. [11] - Maximum charging rate of 50 kW. [11] - Maximum discharge rate of 100 kW. [11] - Lifetime of seven years for a second-life battery used for energy management. [38]
Consumption Data for the School	- The energy consumption of Skavanger School is based on a energy simulation performed by Sweco in SIMIEN in Appendix C. - The energy consumption for the school is assumed to remain the same each year over the lifetime. [11]
Prices	- Prices for solar PV panels and battery was based on Sweco's experience from previous projects. [11] - Price for hydropower is based on Sweco's report, and their previous experience. [11] - Prices for electricity are based upon Nord Pool's spot prices in the Oslo bidding area (NO1 in Table 2.10). [46] - 0.8 %, 0 % and 3.5 % increase in the spot prices per year when using data from 2008, 2010 and 2015, respectively. [11] - Battery price decrease of 3.41 % per year over 25 years. [35] - Inflation is assumed to be a 2% increase each year. [11]

4 Results

This section of the bachelor thesis cover the results from the simulation model. Key numbers relevant to the thesis statement are presented, alongside graphical visualisations regarding energy production, consumption, import, export and battery charge.

4.1 Overview of Key Results

An overview of the results from the simulations of the different scenarios are presented in Table 4.1, 4.2, 4.3 and 4.4. As explained in Section 3.1, scenarios 1-A and 1-B consist of 959 m^2 of solar PV and scenarios 2-A and 2-B consist of 600 m^2 of solar PV. A-Scenarios include 150 kWh battery and B-scenarios includes a 75 kWh battery. For all the scenarios, a 40 % reduction in price is applied to the initial investment cost, due to the economic support from Enova.

Table 4.1: *The output from the simulation of the energy system at Skavanger School. Scenarios 1-A and 1-B consist of 959 m^2 of solar PV and Scenarios 2-A and 2-B consist of 600 m^2 of solar PV. A-Scenarios include 150 kWh battery and B-scenarios includes a 75 kWh battery.*

Scenario	Self Sufficiency Without Battery [%]	Self Sufficiency with Battery [%]	Total Energy Produced Annually [kWh]	Total Energy Used from Battery [kWh]	Total Energy Exported [kWh]
Original	32.73	-	139 300	-	89 186
Hydro	90.28	-	86 722	-	0
Hydro-A	90.28	98.38	119 270	32 403	0
1-A	95.87	99.48	214 540	15 568	88 946
1-B	95.87	98.31	209 640	10 739	88 952
2-A	95.29	99.35	169 610	17 520	44 574
2-B	95.29	97.94	163 710	11 678	44 591

In scenario Original taken from Rambøll's report in Appendix A, the calculated production from the solar PV panels is 134 266 kWh, while in Table 4.1 it is calculated to be 139 300 kWh from PVGIS. The energy system achieves a self sufficiency of 32.73 % and exports 89 186 kWh over a year.

For scenario Hydro-A, the simulation gives a self sufficiency of 98.38 %, but the electricity produced is only 119 270 kWh. Even though scenario Original has a higher energy production than scenario Hydro-A, the self sufficiency is much higher for Hydro-A.

Scenario 1-A produces 214 540 kWh annually and has a self sufficiency of 99.48 % with a 150 kWh battery. The battery delivers 15 568 kWh to the school and 88 946 kWh is exported from the energy system every year. For the 75 kWh battery in Scenario 1-B, the self sufficiency is 98.31 %, the energy produced is 209 640 kWh and 10 739 kWh is used from the battery. Without the battery, the self sufficiency is 95.87 %.

In Scenario 2-A the energy system produces 169 610 kWh and uses 17 520 kWh from the battery, with a self sufficiency of 99.35 % and export of 44 574 kWh. For 2-B, the production is approximately 6 000 kWh lower, and uses around 6 000 kWh less from the battery, while having a self sufficiency of 97.94 % and exports 44 574 kWh. For the same energy system without any battery the self sufficiency is 95.61 %.

Hydro-A is the scenario which uses the battery the most. 32 403 kWh is used from the battery in Hydro-A which is close to double of the next highest scenario, 2-A, with 17 520 kWh used. The scenario with the least energy used from battery is 1-B with 10 739 kWh.

Table 4.2: *The output from the economic simulation of the energy system at Skavanger School. Scenarios 1-A and 1-B consist of 959 m^2 of solar PV and Scenarios 2-A and 2-B consist of 600 m^2 of solar PV. A-Scenarios include 150 kWh battery and B-scenarios includes a 75 kWh battery.*

Scenario	Electricity Bill for One Year [NOK/year]	Electricity Bill over 25 Years [NOK]	Total Installation and Maintenance Cost [NOK]	Total Life-time Cost [NOK]
Original	79 551	2 586 500	1 663 900	4 250 400
Hydro	66 286	2 080 900	1 478 400	3 559 300
Hydro-A	30 709	985 560	2 564 400	3 550 000
1-A	-12 934	-264 410	4 228 300	3 963 900
1-B	-2 725	57 367	3 685 300	3 742 700
2-A	5 699	262 760	3 601 700	3 864 400
2-B	15 603	572 200	3 058 600	3 630 800

As seen in Table 4.2, the total installation and maintenance costs is approximately 200 000 NOK lower for scenario Original compared to scenario Hydro. However, the electricity bill over 25 years is close to 500 000 NOK lower for scenario Hydro. The total lifetime cost, which is the sum of the electricity bill and the installation and maintenance costs over 25 years, is 4 250 400 NOK for scenario Original and 3 559 300 NOK for scenario Hydro, which is more than 700 000 NOK lower.

Scenario 1-A is the most expensive to install and maintain of the scenarios using both solar PV and hydropower, with a total lifetime cost of 3 963 900 NOK. The cheapest of these scenarios is 2-B, with a total lifetime cost comes at 3 630 800 NOK. The electricity bill over 25 years is about ten times higher for 2-B compared to 1-A, however, 2-B is still 300 000 NOK cheaper when looking at the total lifetime cost.

The total cost of installation and maintenance is close to 550 000 NOK higher in the scenarios with a 150 kWh battery compared the ones with 75 kWh. However, when looking at total lifetime cost, the difference in costs are reduced to around 230 000 NOK.

In scenario Hydro-A, the cost of installation and maintenance of having a battery with 150 kWh capacity is close to 1 100 000 NOK higher than not having a battery. However, the total lifetime cost is 9 000 NOK lower for scenario Hydro-A, compared to scenario Hydro.

Table 4.3: *Economic output if the energy system is not implemented and all the electricity is bought from the grid.*

Spot price (year) [NOK/kWh]	Electricity Bill for One Year [NOK/year]	Electricity Bill over 25 Years [NOK]	Total Installation and Maintenance Cost [NOK]	Total Cost Lifetime [NOK]
0.18 (2015)	125 320	4 285 300	0	4 285 300
0.36 (2008)	146 900	4 533 200	0	4 533 200
0.44 (2010)	166 780	4 897 400	0	4 897 400

Table 4.3 shows the costs of importing all the energy from the grid over 25 years for three different spot prices. The table shows that the difference between a low and high spot price can amount to more than 600 000 NOK over 25 years.

Table 4.4: *The total lifetime cost of each scenario with three different spot prices. The change in costs are only from varying electricity bill as all other factors stay the same. The spot prices used are given in parentheses.*

Scenario	Total Lifetime Cost [NOK] (0.18 NOK/kWh)	Total Lifetime Cost [NOK] (0.36 NOK/kWh)	Total Lifetime Cost [NOK] (0.44 NOK/kWh)
Original	4 312 600	4 250 400	4 266 500
Hydro	3 477 600	3 559 300	3 674 900
Hydro-A	3 529 580	3 550 000	3 576 100
1-A	4 206 296	3 963 900	3 776 300
1-B	3 971 600	3 742 700	3 569 600
2-A	4 001 600	3 864 400	3 787 200
2-B	3 751 170	3 630 800	3 569 200

When the spot price varies, the different configurations of the power system behave differently, as shown in Table 4.4. Scenario Original has close to no change in total lifetime costs with different spot prices. Scenario Hydro and Hydro-A do not sell any energy to the grid, as they have no solar PV panels. This is shown as they both have an increase in cost when increasing spot price. Scenario Hydro increases the total costs by approximately 200 000 NOK going from the low to the high spot price, while Hydro-A has an increase of less than 50 000 NOK.

Scenario 1-A, 1-B, 2-A and 2-B are affected differently. These have economic gains from a spot price increase, but to a varied extent. Scenario 1-A and 1-B, which has a higher solar production and therefore a higher export, has the highest economic gains from a spot price increase. This is shown with a reduction of total lifetime costs of close to 400 000 NOK in both scenario 1-A and 1-B. Scenario 2-A and 2-B have a similar trend, but less solar production leads to a lower reduction in total lifetime cost of approximately 200 000 NOK. The difference between A and B for both scenarios are around 30 000 NOK, with the A-scenarios being the cheapest.

4.2 Scenario: Original

In scenario Original, as proposed by Rambøll, the energy system for Skavanger School would consist of 959 m^2 of solar PV panels, without a hydropower plant or a battery. The visualisation of the different scenarios have been performed using two graphs with different resolutions, one showing a week in March and one showing a whole year. Power produced from the solar PV cells has been coloured in yellow and is plotted with one bar per hour. The amount of power required by Skavanger School for each hour is plotted as a red line graph. The purple bars show the hourly imported and exported power, where positive values equal exported power and negative values show imported power.

Figure 4.1 shows a plot of a week in March. The line graph shows that most of the demand is from 08:00 to 16:00, with a peak in demand in the morning. From Wednesday through Friday, the pattern for energy production from the solar PV cells and energy demand are very similar to each other. This shows that for most of the hours of a school day, the solar production covers the demand. However, during the first and last hours of the school day, the solar production is lower, resulting in a need for importing power. These peak loads are on up to 40 kW per hour for one or two hours per day. In the middle of the day, the production from the solar PV panels exceed the school's demand, resulting in an export of power to the grid and peaking in the middle of the day. This excess production results in a export peak of up to 80 kW per hour around mid day with normal solar conditions.

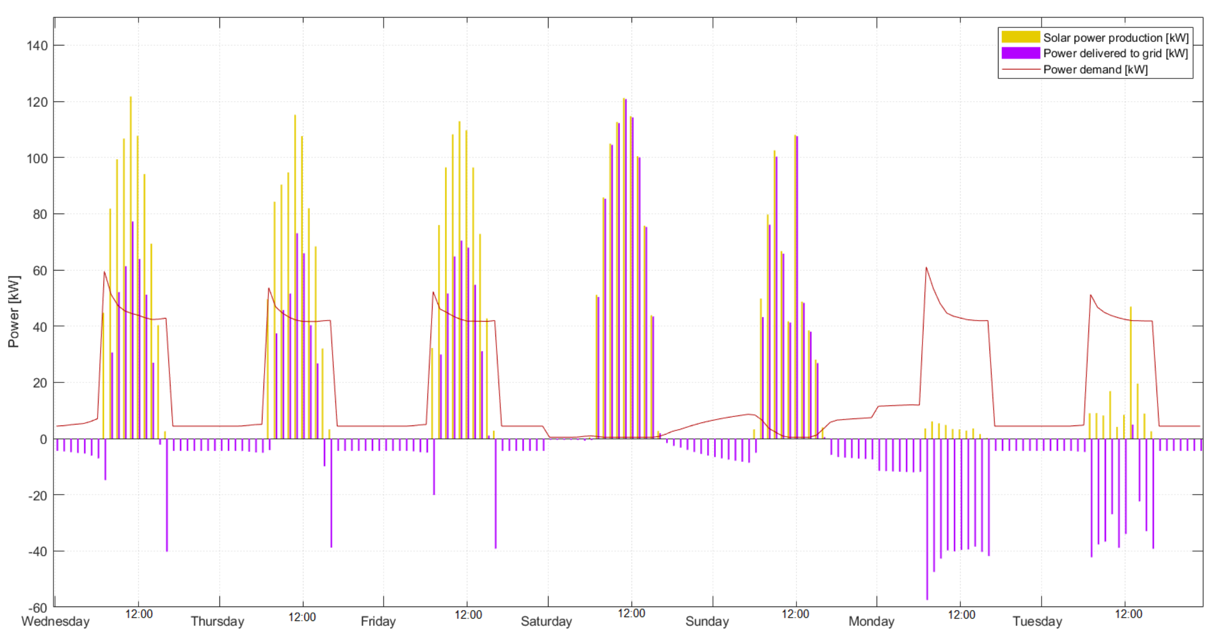

Figure 4.1: *The Original scenario simulated with 959 m^2 of solar PV production over a week. Yellow represents hourly solar power production, red represents the hourly power demand of the school and purple is the hourly power delivered or taken from/to the grid.*

During the nights and weekend, there are close to no power demand at the school. There is no solar power production during night time and all of the electricity has to be imported from the grid. During the weekend, close to all of the power produced is exported to the grid, reaching a peak of nearly 120 kW. For the following Monday and Tuesday, the solar conditions are less optimal resulting in lower power production. This results in a higher peak load during the first hour and more import during the whole school day for these days.

Figure 4.2 displays the net imported and exported electric energy in addition to the daily energy production over a year for the Original scenario. This graph shows that almost all electric energy is imported during the period from November to March. The purple indicate that 400 to 600 kWh are imported per day in that period. From April to July, there are some days that requires energy import, but many days end up with a net export to the grid because of better solar conditions. During the summer, there is almost no energy demand from the school resulting in close to all of the produced power being exported to the grid.

The number of negative purple columns can be related to the self sufficiency of 32.74 % in Table 4.1. The majority of the total production from the energy system in the Original scenario is in the period between April and September. There is a large amount of production in July and August. The difference in supply and demand in the summer months result in a large amount of unused power which is exported to the grid.

Figure 4.2: *The Original scenario simulated with 959* m^2 *of solar PV production for a year. Yellow represents total daily solar energy production, red represents total daily energy demand of the school and purple is the total daily energy delivered or taken from/to the grid.*

4.3 Scenario: Hydro

In this scenario Hydro-A, the energy system consists of a 150 kWh battery along with the hydropower plant. The battery charge is represented as a percentage of the maximum charge. Visually this is represented by a grey area graph. In the weekly graphs, hydropower production is presented with green bars.

Figure 4.3 visualises the Hydro-A scenario, where the battery discharges when the demand is higher than hydropower production during the middle of the day, and charges after the demand drops in the afternoon. From Wednesday to Friday, the hydropower plant runs at full capacity from 08:00 to almost midnight. During the first seven hours, the battery discharges to fill the gap between the hydropower production and the demand. The last three hours of demand, the school has to import a small amount of power. During the weekend, there is close to no demand, leading to the battery being charged to full capacity. For the following days, the same pattern as described for Wednesday to Friday occurs.

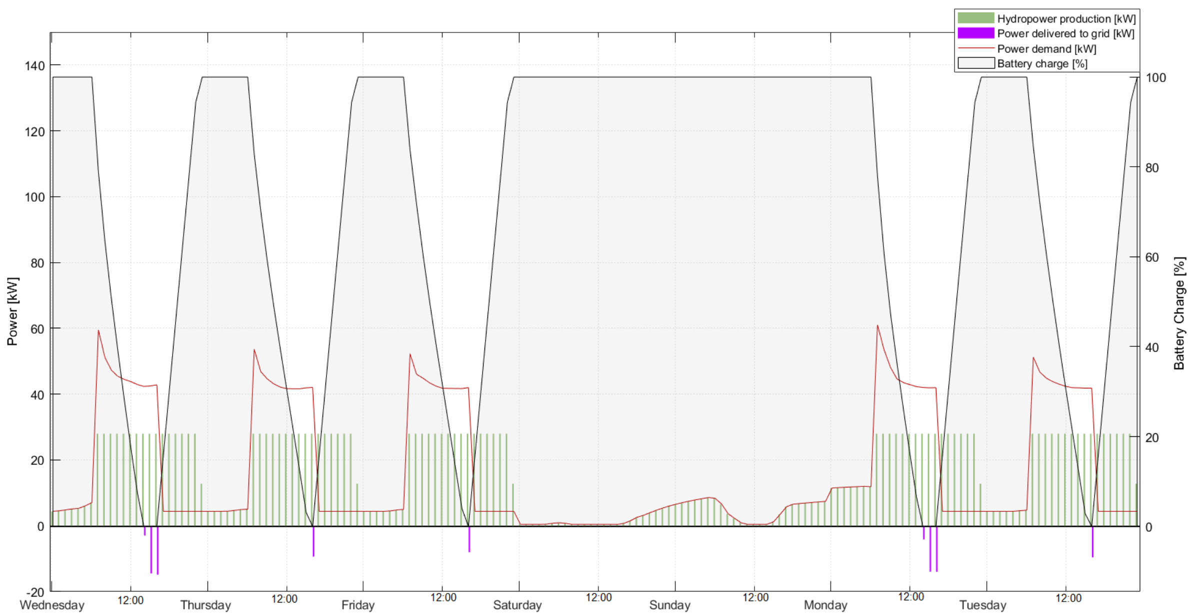

Figure 4.3: *Scenario Hydro-A simulated with the hydropower plant and a 150 kWh battery for a week. Green represents hourly hydropower production, red represents hourly power demand of the school and grey is charge of the battery*

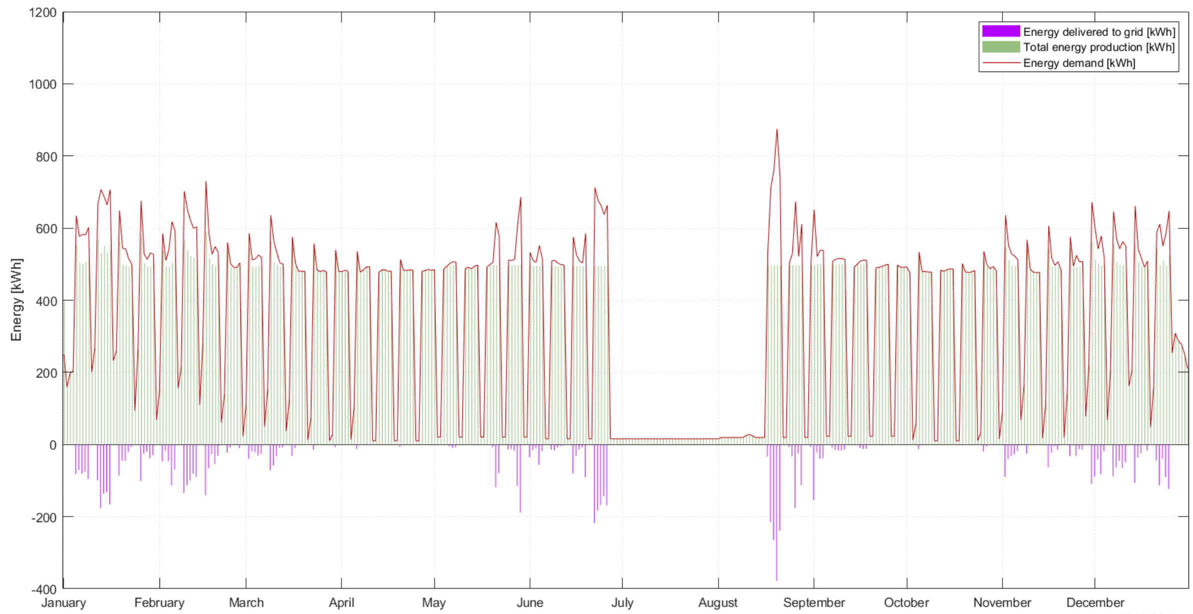

Figure 4.4: *Scenario Hydro-A simulated with the hydropower plant and a 150 kWh battery for a year. Green represents total daily energy production from the hydropower plant, red represents total daily energy demand of the school and purple is the total daily energy delivered or taken from/to the grid.*

Figure 4.4 illustrates that the energy system does not import energy from the grid for a large portion of the year. The total energy production is close to the same as the demand. Most of the imported energy is during the winter in addition to right before and after the summer holiday.

Based on the values from Sweco's report on micro hydropower, found in Appendix B, the annual potential for electricity production based on inflow is 157 195 kWh. The annual unused water from inflow for electricity production for the different scenarios are shown in Table 4.5. When introducing a battery, the hydropower plant is used to charge it, leading to more of the water being used for energy production. The unused water is stored in the reservoir for later use or to be used by other parties.

Table 4.5: *Electricity production and unused water from inflow for scenario Hydro and Hydro-A*

Scenario	Electricity Production [kWh/year]	Unused Water from Inflow [kWh/year]
Hydro-A	119 270	37 925
Hydro	86 722	70 473

4.4 Scenario: 1

Scenario 1-A features the hydropower plant, 959 m^2 of solar PV panels and a 150 kWh battery. For the week in March, there is no need to import energy from the grid, as seen in Figure 4.5. From Wednesday to the end of Friday, the solar power production is approximately the same for each day, with the peaks reaching around 120 kW. The hydropower plant runs during the night to meet the demand, and shuts down as the solar power production surpasses the demand in the morning. When solar power production is reduced in the afternoon, the hydropower plant starts up. For the hours where solar production exceeds demand, the excess energy is exported to the grid. At 16:00, there is a 10 kW gap between the total production and the demand. To fill that gap, the battery is used which can be seen in Figure 4.5 as the small decreases of the grey area. The battery is charged by the hydropower plant the next hour. This shows that the battery stays mostly unused in days with good solar conditions.

During the weekend, there is almost no power demand and close to all the power produced by the solar PV panels is exported to the grid. The Sunday has less production than on Saturday, which results in less power being exported on the Sunday.

The battery close to fully discharges during the Monday, but after 16:00, when the demand decreases, it is able to recharge fully. On Tuesday, there is some production from the solar PV panels which results in less dependency on the battery to fill the power demand.

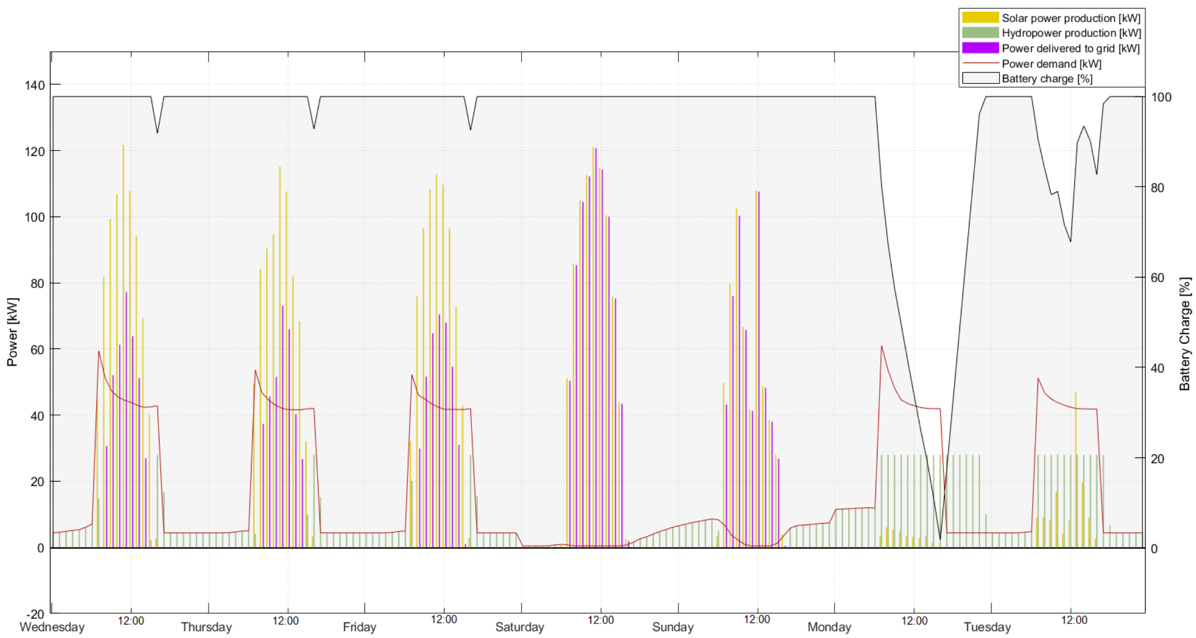

Figure 4.5: *1-A simulated with the hydropower plant, 959 m^2 of solar PV and a 150 kWh battery for a week. Yellow represents hourly solar power production, green represents hourly hydropower, red represents hourly power demand of the school, grey is the charge of battery and purple is the hourly power delivered or taken from/to the grid.*

The performance of scenario 1-A over a year, can be seen in Figure 4.6. It shows the need for energy import is very small. Almost all import of energy is in December and January, with a few days in November to February and one day of import in September. The few days where there are a need for imported energy, the amount is around 100 kWh per day. Over the year, most of the export comes from March to September. From late June to the middle of August almost all energy produced is exported to the grid because the demand becomes very low. The highest peaks of export in this scenario are between 800 and 1000 kWh per day, at the most.

Figure 4.6: *1-A simulated with the hydropower plant, 959 m² of solar PV and a 150 kWh battery over a year. Green represents total daily energy production, red represents total daily energy demand of the school and purple is the energy total daily delivered or taken from/to the grid.*

4.5 Scenario: 2

Scenario 2-A looks at an energy system consisting of the hydropower plant in combination with 600 m^2 of solar power and a 150 kWh battery. The general trend of 1-A in Figure 4.5 is the same for 2-A in Figure 4.7. How the hydropower plant runs, the solar PV panels produce and the battery charges and discharges in 2-A, have similar characteristics to Scenario 1, described in Section 4.4. For the selected week in March, seen in Figure 4.7, there is no need to import energy, except for one hour with about 10 kW. With a battery capacity of 150 kWh, the battery is fully charged or close to it most of the time. The combination of solar power and hydropower produces more power per hour than what is needed by the school. During the weekend, strong solar conditions combined with a low need for power leads to power being exported.

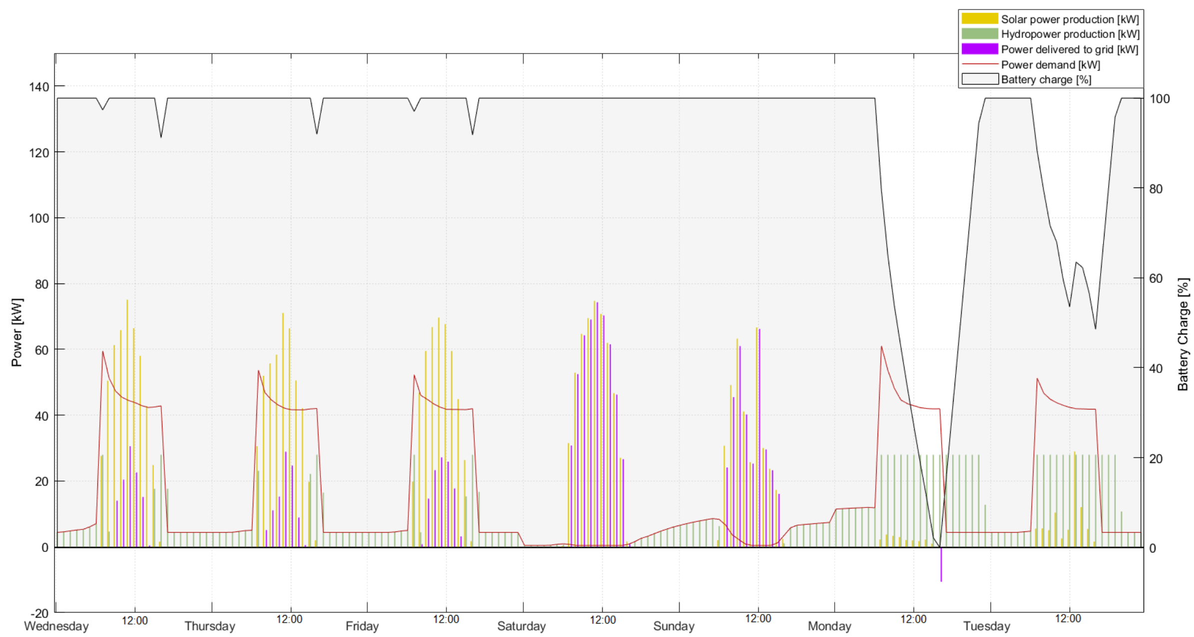

Figure 4.7: *2-A simulated with the hydropower plant, 600 m^2 of solar PV and a 150 kWh battery for a week. Yellow represents hourly solar power production, green represents hourly hydropower production, red represents hourly power demand of the school, grey is the charge of battery and purple is the hourly power delivered or taken from/to the grid.*

With the lower battery capacity of 75 kWh in 2-B, as seen in Figure 4.8, the system has more trouble providing sufficient power on Monday and Tuesday. When there is low production from the solar PV panels, such as during the Monday, more power has to be imported from the grid than in scenario 2-A, shown in Figure 4.7. Scenario 2-B sees more variation in battery charge, especially on days with low solar production.

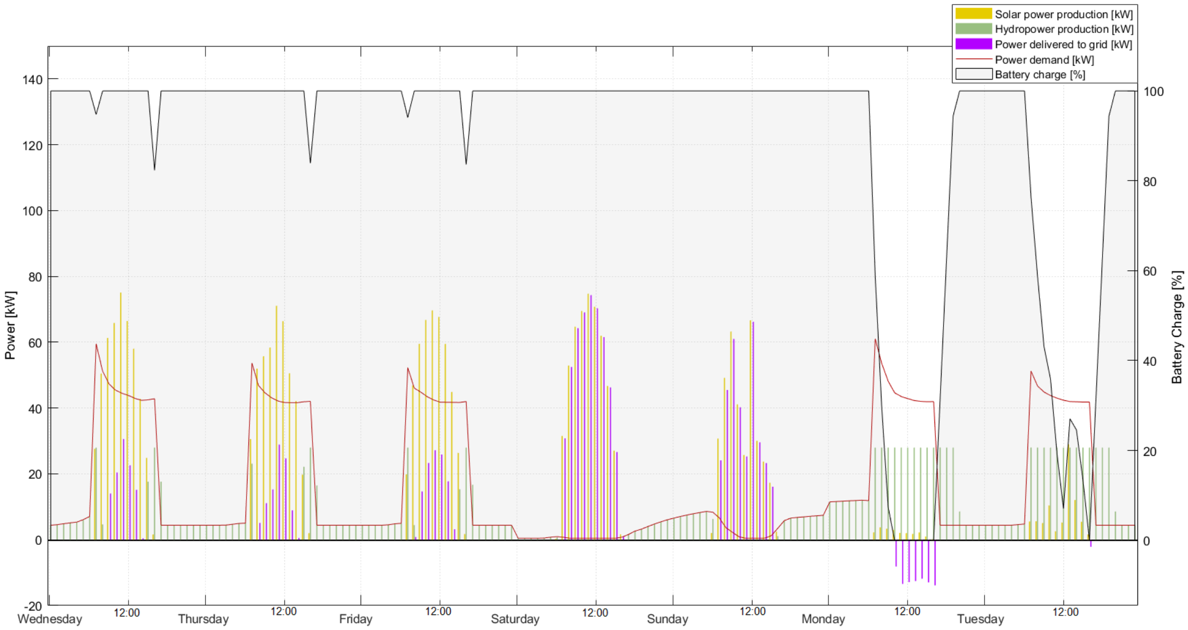

Figure 4.8: *2-B simulated with the hydropower plant, 600 m² of solar PV and a 75 kWh battery for a week. Yellow represents hourly solar power production, green represents hourly hydropower production, red represents hourly power demand of the school, grey is the charge of battery and purple is the hourly power delivered or taken from/to the grid.*

As seen in Figure 4.9, the winter months have a higher consumption of energy than the rest of the year. Solar production is also low in these periods. The combination of these factors result in energy being imported from the grid to meet the energy demand. In contrast, a large amount of energy is exported during July and early in August. The highest peaks of export in this scenario are between 400 and 600 kWh per day, at the most.

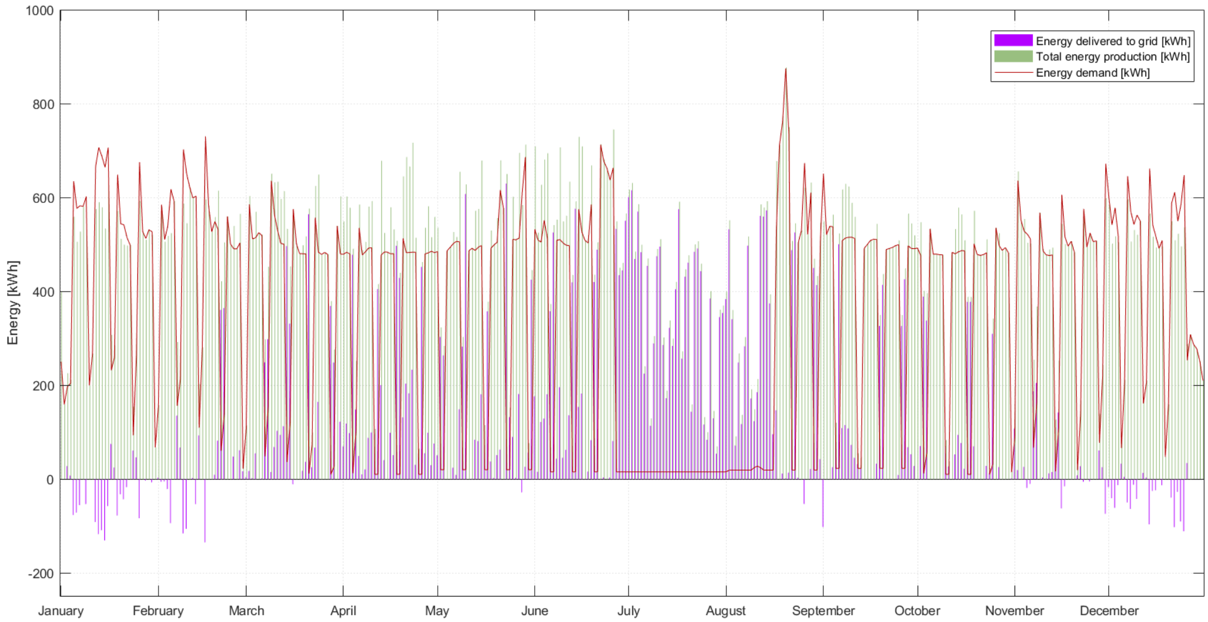

Figure 4.9: *2-A simulated with the hydropower plant, 600 m^2 and a 150 kWh battery for a year. Green represents daily total energy production, red represents daily total energy demand of the school and purple is the daily total energy delivered or taken from/to the grid.*

With a 75 kWh battery, as seen in Figure 4.10, more energy has to be imported. Especially during the winter. The time when import of energy takes place is generally the same, but the amount needed to imported is larger.

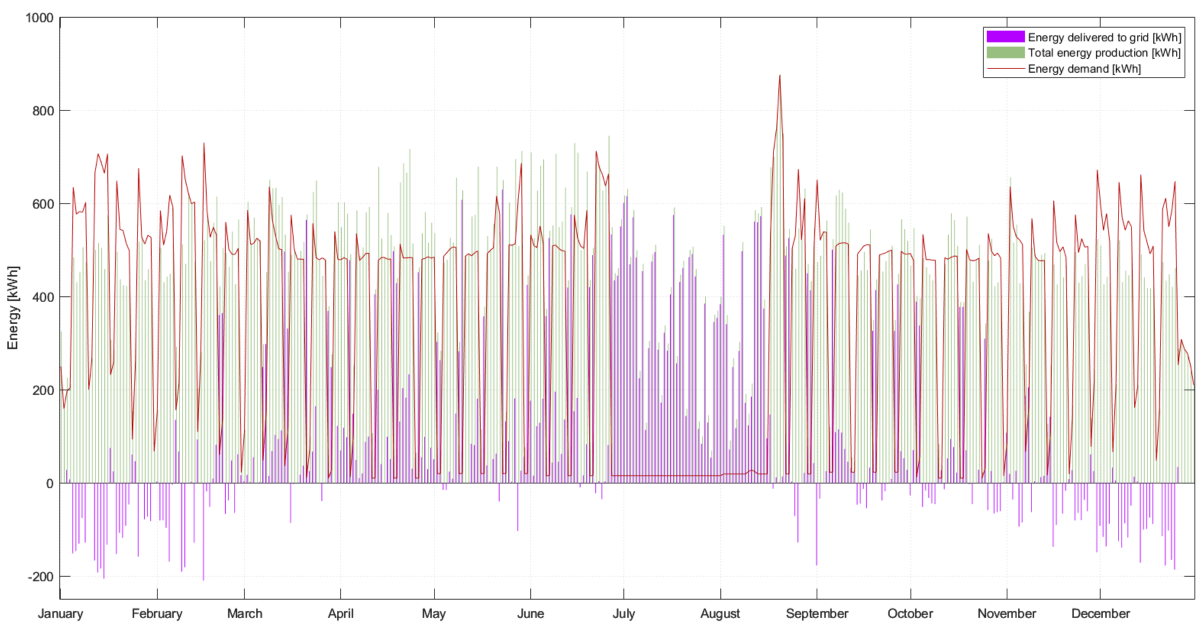

Figure 4.10: *2-B simulated with the hydropower plant, 600 m^2 and a 75 kWh battery for a year. Green represents daily total energy production, red represents daily total energy demand of the school and purple is the daily total energy delivered or taken from/to the grid*

4.6 Summary of the Results

The scenarios perform differently which results in a variety of lifetime costs. The green colour illustrates which options are the most favourable, the yellow highlights the less favourable options and the red highlights the least favourable options. For self sufficiency, the green options is for values over 95 %, yellow for 90-95 %, and red for less than 90 %. For the total lifetime cost, values that are within 200 000 NOK of the cheapest option are green, between 200 000 and 400 000 NOK are yellow, and if they are more than 400 000 NOK higher, they are red.

For cost sensitivity, the difference between the highest and lowest total lifetime cost with the different prices for each scenario are used. Figure 4.11 shows how the scenarios rate against each other's in regard to self sufficiency, total lifetime cost and cost sensitivity. The figure shows that scenario Hydro-A has the most green squares, representing a high competitiveness compared to the other scenarios. Scenario Original has the most red squares, while the rest show a combination of green, yellow and red squares. All scenarios except scenario Original and scenario Hydro have a competitive self sufficiency. Several of the scenarios with a combination of solar PV panels, a hydropower plant and a battery have a high cost sensitivity and are more competitive with higher spot prices than with low and medium spot prices. The colour coding of Figure 4.11 is summarised in Figure 4.12.

Scenarios	Self Sufficiency*	Total Lifetime Cost (Low)**	Total Lifetime Cost (Med)**	Total Lifetime Cost (High)**	Lowest Cost Sensitivity***
Original	[red]	[red]	[red]	[red]	[green]
Hydro	[yellow]	[green]	[green]	[green]	[green]
Hydro-A	[green]	[green]	[green]	[green]	[green]
1-A	[green]	[red]	[red]	[yellow]	[red]
1-B	[green]	[red]	[green]	[green]	[red]
2-A	[green]	[red]	[yellow]	[yellow]	[yellow]
2-B	[green]	[yellow]	[green]	[green]	[green]

Figure 4.11: *Summary of the self sufficiency and lifetime costs from the different scenarios. *For self sufficiency, found in Table 4.1, green is > 95 %, yellow is 90-95 % and red is < 90 %. **For lifetime costs, green means the value is within 200 000 NOK of the cheapest, yellow means 200 000 between 400 000 NOK and red means more than 400 000 NOK. The specifications "low", "med" and "high" for total lifetime cost, which can be found in Table 4.4, refer to different levels of spot prices mentioned in Table 2.11. ***Cost sensitivity is based on the difference between the highest and lowest total lifetime cost with green being less than 200 000 NOK, yellow being 200 000 to 400 000 NOK and red being above 400 000 NOK.*

Colour	Self Sufficiency Range [%]	Lifetime Cost Range [NOK]	Cost Sensitivity Range [NOK]
[green]	> 95	< 200 000	< 200 000
[yellow]	90-95	200 000 - 400 000	200 000 - 400 000
[red]	< 90	> 400 000	> 400 000

Figure 4.12: *Description of the colours used in Figure 4.11. Lifetime cost range and cost sensitivity is based difference from the cheapest value.*

5 Discussion

In this section, the results combined with the methodology and relevant theory will be considered to evaluate the strengths and weaknesses of the results. The first part will address the different assumptions made. Additionally, the simulation model will be evaluated before the performance of the different energy systems is discussed. The section will end with topics which can be investigated more thoroughly which this thesis has not included or focused on.

5.1 The Assumptions

Assumptions are key elements defining the results in the bachelor thesis. The purpose of the assumptions is to simplify some of the calculations to make it easier to find presentable and valid results. These assumptions have impacted the results, some more than others. Considering that the economic calculations made are for a 25 year period, there is a wide span of time for prices and other factors to change.

When starting this project, 2015 was used as the base for the solar data as mentioned in Section 2.2.2. It is only one year and the solar radiation must be expected to vary considerably from year to year. In addition to this, it is not known what year the simulated values for energy demand are based on. If they are based on a year with different temperature characteristics than 2015, it can lead to inaccurate results. The risk of this can be reduced by taking the average temperature over several years, but there will still be uncertainty in the results. For example, global warming means that historical temperatures will not necessarily be representative of the future. These are conditions and parameters that are difficult to quantify since they are stochastic and most likely also non-stationary. Over a period of 25 years, which is the perspective used in this project, this can lead to significant discrepancies between the simulation results and real life. The inflow of water to the reservoir is also assumed to be the same each year. This too is a simplification, and variations must be expected from year to year due to differences in rainfall and temperature. However, as there is a large excess of water in the reservoir, the effect of this simplification is close to negligible because the hydropower production is not affected by increasing the inflow.

For the solar power production data, 14 % system loss and optimal azimuth and slope is assumed. The system loss will vary to some degree from system to system, but 14 % is the most common number used by companies like Sweco. To change the system loss to another number could make the results more unpredictable compared to calculations made by Sweco and Rambøll. Which values the slope and azimuth will have in reality is not known, but it is fair to assume that it will be close to optimal. The slope and azimuth could be changed to alter the production profile to better fit the consumption pattern at the school. This could improve the self sufficiency, and lower the need for imported power. The total energy production from the solar PV cells would be lower, but the power produced could cover more of the schools demand.

Both the energy consumption profile and the annual amount of energy consumed by Skavanger school is assumed to be the same each year. It is likely that the pattern of usage and what equipment the school uses would remain relatively similar over 25 years, and building according to the FutureBuilt standard entails a low energy usage for heating.

A real life battery will have variations in performance over its lifetime, compared to the one in this model. There will be a drop in performance each year, in addition to not having 100 % round-trip efficiency nor using 100 % of the capacity when charging and discharging. Taking this into account, would make the simulation much more complex and harder to work with. This affects the results in terms of self sufficiency and electricity bill over 25 years, but to an unknown extent. However, the objective of this thesis is not to simulate a realistic battery, but to see the general effect of it and make a decision on which battery size that suits the school best. Therefore, the choice of simplifying the simulation, while it still being representative for how the battery affects the energy system, was made.

When simulating the price developments for batteries and electricity price, a yearly linear change in price was assumed. The yearly average spot price, found in Figure 2.11, shows that prices may increase or decrease substantially from year to year. Attempting to predict this pattern 25 years into the future is impossible and the end result will be inaccurate. However, based on reports from NVE in Section 2.5, the average spot price for electricity is expected to rise in the future. Therefore, a fixed yearly increase was used. As an average increase per year is used, there will be a deviance in the values for specific years. However, the resulting spot price after 25 years is within the projected range presented by NVE in their report. This approach was used on the pricing data from 2008, 2010 and 2015, resulting in a differing yearly increase for each data set. After 25 years, the average spot prices end up being approximately the same, which was done to ensure that the pricing data stays within a realistic range compared to the estimates made by NVE in their report.

Similarly, it may not be realistic to expect the cost of battery packs to experience a price drop similar to previous years. However, a drop in price to some extent is reasonable to expect. The different forecasts provide a range for how the price for Li-ion battery packs can develop. For the simulation model, a 3.41 % yearly decrease was assumed. This value was chosen as a conservative estimate based on the different price forecasts, mentioned in Section 2.4.2, and leads to a 50 % drop in price over a 20 year period.

For a project like this, which has substantial economic costs associated with it, having conservative scenarios can be favourable. By calculating the costs in such a manner, it limits the likelihood of the project being more expensive than planned. If there was a range of prices listed for a component, the most expensive option was chosen. However, the installation costs of the different components are most likely accurate since they are taken from the suppliers or previous projects Sweco has worked on. The cost of installation for the hydropower plant is increased by 15 % to compensate for unexpected expenditures. Creating the scenarios in this way run the risk of producing results that indicate a less economically sound energy system than what the actual system will be. Overall, being conservative can be seen as the most favourable approach, due the simulation being based upon many assumptions that could affect the economics of the final result.

Due to this bachelor thesis being based on several reports. There is a possibility that assumptions and simplifications used in these reports impact the results in this thesis. If Rambøll and Sweco also made conservative assumptions in their reports, the results from this bachelor thesis could be overly conservative. A consequence of this could be that the economic performance of the energy system is much better than concluded. Quantifying the impact these markups have on the results are difficult. This could suggest that there will be some difference between the results generated by the simulation model and results gained from running the energy system in real life.

5.2 The Model and Simulations

When creating a simulation model, there is a chance of making errors in the code which can be hard to find. This could be from spelling mistakes, a wrong use of symbols or something that has been forgotten. The results were thoroughly analysed along with supervisors, reflected upon and compared to literature and known trends. This increases the chance of avoiding potential mistakes. On the other hand, as some of the results are challenging to double check with an external computation or source, there will always be a chance of making errors.

An important aspect to consider is how feasible it is to implement the model in real life. The simulation is based on the possibility of monitoring the battery charge, the amount of water in the reservoir, the local energy production as well as the energy demand. This could be possible, however it may prove a challenge to regulate this in real time as there can be variances on a minute to minute basis. Any change in values on a lower time resolution than hourly could lead to a change in amount of electricity sold and bought from the grid. The system could be unable to adjust quickly enough to the changes if the values are not in real-time. However, the simulation model indicates what may be theoretically possible and what the potential of the energy system is. The objective for this thesis is not to come with a control system for the energy system and therefore has this has not been prioritised.

The aim of the project affected how the simulation was constructed and which results that were acquired. This thesis focuses on self sufficiency and lifetime costs. As an effect of this, the simulation only runs the hydropower plant when there is a power demand, and shuts down when there is no demand. In addition to this, the battery is charged or discharged whenever there is a excess or a shortage of energy. This simplified battery model may be less optimal if there is a goal to reduce the highest power peaks of a day. A model focused on peak shaving could save a percentage of the charge in the battery for the afternoon where the consumption often increases while the solar power production decreases. There may also be other ways of regulating this system that could be better economically. The economical benefits of running the simulation model as done in this thesis may change over time, as the pricing structure of the electricity bill can change in the future, making it more expensive for higher power peaks.

The model is based on only using the hydropower for energy demand and charging the battery. The thesis prioritises self sufficiency, and the hydropower will therefore only run to meet the school's demand, or if the battery has spare capacity. In addition to this, the focus on saving excess water for later use has been prioritised over increasing the hydropower production and selling more electricity to the grid. The reason for this is that one of the focus areas for Kongsberg municipality regarding this project was to have high self sufficiency. Due to the cost associated with operating the hydropower plant being constant, increasing energy production would improve the economical performance. On the other side, the water reservoir is also used by several parties, like the local skiing and sport facilities, which also require a share of the reservoir. For the municipality, which runs the facilities and school, it may be more valuable to keep enough water in the reservoir for later use, to allow for future operations and other usage areas.

5.3 Comparison of the Scenarios

Examining how the performance of the energy system differs by altering the scenarios, highlight how the components work together and how economically viable they are. Even though both the hydropower plant and the solar PV panels generate energy, they operate in different ways. Both hydropower and solar power depend on an intermittent source. Hydropower depends on the inflow of water while solar power need irradiance from the Sun to function. A battery was included to see how it affects the performance in terms of self sufficiency and lifetime costs, as it enables the system to utilise more of the local production. To visualise the results, a graph for one week and one year was chosen. The yearly graph illustrates the general trends over a year with the different elements, and the weekly graph shows how the system works on given days. The week in March was chosen because it includes days with both good and poor solar power production, and will therefore illustrate how the system will interact with varying weather conditions. The first days of the graph, which has good solar conditions, could represent the summer half of the year. The last couple of days of the graph illustrates the system with poor solar conditions, representing the winter half of the year. The graph also shows how the energy system operates during weekdays, how the weekend affects the performance and how the following days benefit from a fully charged battery.

The graph over a year is measured in kWh per day, while the week graph is measured in kW per hour. When looking at the graphs, the week graph shows the exact power production, demand and battery charge per hour. The graph over a year shows the net production and net export or import during a day. Therefore, the year graphs can not be fully used to compare the different scenarios with self sufficiency in mind. The general trend will be shown, but it will not be exact as the formula for self sufficiency, described in Section 2.6, is measured using hourly values.

Scenarios which include 959 m^2 of solar PV panels have an instantaneous export of power of over 100 kW during some hours where solar conditions are good and power demand for the school is low. This is a problem as it violates the terms for being a prosumer, as stated in Section 2.5. Resolving this would require cutting export of power if the instantaneous value exceeds 100 kW. If not, the school would have to be registered as a power plant and not a prosumer and would need licensing from NVE. This is not beneficial for the school regarding the export of energy and the scenarios will become more expensive.

5.3.1 Comparing the Performance of the Energy Systems of Scenario Original and Hydro

For the energy system at Skavanger School, the hydropower plant is able to produce energy at a more constant and predictable rate compared to the solar PV panels. This difference is highlighted in several graphs in Section 4, showing the week in March for different scenarios. The pattern of production for the hydropower plant remains relatively constant, producing as much as possible to cover energy demand in addition to charging the battery, as long as there is unused water in the reservoir. The solar PV panels on the other hand, see a much bigger change in its production profile over a year. As seen in Figure 2.6, the production of energy from the solar PV panels increase throughout the year, peaking in the summer months of June and July, and tapering down towards the winter months. The Hydro-A scenario covers the demand with hydropower production for a larger portion of the day than the scenario Original, but the Original scenario has higher production at its peak.

Considering the main purpose for the components is to provide Skavanger School with energy, the optimal energy source would be one that could match the energy demand at all times, leading to a self sufficiency of 100 %. From Figure 2.2, the trend is that the school consumes more energy during winter months, compared to a consumption of close to zero in July and August. This pattern is the opposite of the production pattern of the solar panels, meaning the period of the year where energy production from solar PV is high, energy consumption is low. From a self sufficiency standpoint, this is not ideal. The weakness of a system that only utilises solar power is highlighted in Table 4.1, where the self sufficiency of scenario Original is 32.73 %. If the objective was solely to fulfil the energy production requirement from the FutureBuilt standard and not achieve a high self sufficiency, solar PV panels could be a viable option. The hydropower plant, on the other hand, provide a high rate of self sufficiency, both with and without a battery. The Hydro scenario, where the energy system only uses the hydropower plant as a source for energy generation, has a self sufficiency of 90.28 %.

5.3.2 Comparing the Performance of the Energy Systems with Different Solar PV Areas

Scenario 1-A, 1-B, 2-A and 2-B have complex energy systems, which include a hydropower plant, solar PV panels and a battery, and are visualised in the graphs in Section 4. The hydropower plant can provide a very consistent source of energy, which is a substantial part of the power required by the school on a hourly basis. During the winter months, close to all of the produced power is from the hydropower plant. During the summer months, the hydropower plant is only used to meet the demand at times of the day when the solar PV does not produce enough electricity to match the demand.

As scenario Hydro is without solar PV panels, it does not export any energy to the grid, as seen in Table 4.1. However, scenario 1-A and 1-B, which has 959 m^2 of solar PV panels, have a large amount of exported energy during the summer months. These scenarios export as much electricity as the Original scenario, but as the self sufficiency is higher, they import way less electricity from the grid. As the change in solar irradiance over a year is quite substantial, a system which covers the energy demand in most of the winter months, will have an extreme overproduction during the summer months. These two scenarios have a small increase in self sufficiency from 99.35 % to 99.48 % with an increase of 359 m^2 of solar PV panels. This amounts to an additional overproduction of over 40 000 kWh, which is sold to the grid. This could imply that installing more solar PV panels in an attempt to achieve 100 % self sufficiency would only result in a massive overproduction in the summer, while only barely increasing production in the winter.

5.3.3 Comparing the Performance of the Energy Systems with Different Battery Capacities

Scenario Hydro has a production of 86 722 kWh in a year. The main limiting factor of this scenario is that the 28 kW of maximum production is lower than the demand for most of the hours during the day, while having a large amount of unused potential during the night. Introducing a 150 kWh battery, which is charged in the evenings and nights as done in scenario Hydro-A, allows the system to increase the yearly production to 119 270 kWh. As the hydropower is only used for local demand, the increase shows that introduction of a battery increases the local production with 27 %, thus also reducing the yearly electricity bill by more than 50 %, which amounts for a reduction of more than 1 000 000 NOK over 25 years. These results show that introducing a battery will improve both production and self sufficiency by using more locally produced energy, in addition to lowering the electricity bill substantially.

The battery allows scenario Hydro-A to have an electricity production of 119 270 kWh per year, which is 32 548 kWh more than scenario Hydro. However, both scenarios do not produce enough to fulfil the FutureBuilt requirement of 134 266 kWh of local energy production per year. This is a problem, but there are options that can solve this. Increasing the battery capacity further would in turn increase the production from the hydropower, but at an increased cost. Another option is to adjust the simulation to produce more power than needed at no extra cost. This is possible, as the simulation uses less water in a year than the average yearly inflow as seen in subsection 4.3. This shows that there is a potential of an additional 37 925 kWh of hydropower production that could be produced every year based on inflow.

The 150 kWh battery of the A-scenarios is just enough to manage a day with poor solar conditions without needing the grid, before charging fully over night. The 75 kWh battery of the B-scenarios however, depletes twice as fast, resulting in a greater need for energy from the grid. The higher battery capacity comes at a greater cost, but improves the self sufficiency of the system. As the scenarios with solar PV panels have the ability to achieve a production that is high enough for the demand for most days between March and October, the battery will be less essential than in the scenarios with just hydropower. The graphs in Figure 4.7 and Figure 4.10 illustrate how the extra battery capacity improves the self sufficiency. The Monday and Tuesday may represent how the system would work in the winter months, showing how important the battery can be in days like this. As the Wednesday to Sunday may illustrate a summer day, this could imply that the battery would be largely unused in the summer months.

Even though the battery is largely superfluous for periods with strong solar conditions, the system still benefits from the battery in the winter months. This can be seen in Table 4.1, where a capacity increase, raises the self sufficiency from 98.31 % to 99.48 % in scenario 1 and from 97.94 % to 99.35 % in scenario 2. This however, is not a substantial increase, and the higher costs associated with a larger battery may not be justifiable from an economic standpoint.

5.3.4 Economic Comparison of Scenario Original and Hydro

Even though scenario Original produce 139 900 kWh annually compared to Hydro which produces 86 722 kWh, scenario Hydro has a 691 100 NOK lower total lifetime cost. This difference could be caused by the large difference in self sufficiency between the two scenarios. A large amount of the energy produced from scenario Original is exported to the grid, whereas a larger share of the annual energy production from scenario Hydro covers the school's energy demand. This suggests that reducing the amount of energy imported is more profitable than exporting additional energy to the grid.

5.3.5 Economic Comparison of the Scenarios with Different Solar PV Area

Scenario 1-A has 959 m^2 of solar PV which provides a large amount of power production. As 88 946 kWh of the total energy produced is exported, the school will profit from selling energy to the power company. Over 25 years, 1-A makes a net profit of 264 410 NOK on the electricity bill. 2-B on the other hand, has an electricity bill that amounts to a cost of 262 760 NOK over 25 years. Even though there is a large difference in the electricity bill over 25 years in these scenarios, the total lifetime cost of scenario 1-A ends up being higher than 2-A. This suggests that increasing solar power production is not necessarily profitable as there it comes with a large increase in installation and maintenance cost. For this to be a viable option, the gains from increased production have to be higher than the increased installation and maintenance costs. This suggests it is more profitable to cover the schools energy demand rather than overproducing electricity and selling to the grid.

5.3.6 Economic Comparison of the Scenarios with Different Battery Capacities

Introducing a battery in the energy system reduces the need to import energy, and comparing the electricity bill over 25 years illustrates the effect of this. While scenario Hydro has a total electricity bill of approximately 2 100 000 NOK, scenario Hydro-A only requires approximately 1 000 000 NOK to cover the electricity bill over 25 years. However, the potential savings of the reduced electricity bill is negated by the increase in total installation and maintenance cost brought on by the battery. Similarly, when a battery is introduced, the effect this has on the self sufficiency is substantial. In scenario Hydro, where there is no battery, the rate of self sufficiency is 90.28 %. Adding a 150 kWh battery, Hydro-A increases the rate of self sufficiency to 98.38 %. In this case the total lifetime cost is reduced when including a battery, but only by 9 300 NOK.

To examine the economic impact of increasing the battery capacity, it is most apt to compare scenario 1-A to 1-B or 2-A to 2-B. Doing this ensures that the only variable changed is the battery capacity. While a bigger battery capacity does increase the rate of self sufficiency, it is not by much. For example, the difference between self sufficiency for scenario 1-A and 1-B is 1.17 %. The difference in total cost over lifetime is approximately 221 000 NOK in favour of Scenario 1-B. Looking at 2-A and 2-B, there is a similar trend when going from a 150 kWh battery to a 75 kWh battery in terms of total lifetime cost, and self sufficiency. This could indicate that doubling the battery capacity does not yield a significant increase in energy system performance compared to the increased costs.

Comparing Figure 4.9 and Figure 4.10 indicates why there is a small difference between self sufficiency for scenario 2-A and 2-B. Due to how self sufficiency is calculated, the amount of energy exported per hour has no effect on the self sufficiency, as it only measures how much of the demand is covered at any given time. As seen in Figure 4.9 and Figure 4.10 the negative purple bars generally appear in same places, but for scenario 2-B the purple bars are taller. This indicates more energy being imported overall, but the amount of hours where this takes place does not change as much.

Overall, examining how a battery impacts the energy system suggests that including a battery reduces the total lifetime cost, as seen when comparing Scenario Hydro and Hydro-A. However, a 150 kWh battery may not be the optimal capacity, as the total lifetime cost when comparing Scenario 1-A to 1-B and 2-A to 2-B decreases when halving the battery capacity to 75 kWh.

5.3.7 Comparison of Price Sensitivity

The pricing structure when importing energy includes spot price, grid rent, energy tariff, power tariff, consumption tax and VAT. The revenue from selling energy, on the other hand, is based on spot price in addition to a small compensation from the grid operator, as mention in Section 2.5. Additional incentives for exporting energy could be introduced by the government, as more local energy generation reduces energy losses throughout the grid. More local energy production, especially in isolated communities, allows the grid operators to delay improvements to the grid infrastructure. This can be valuable as upgrading the grid can be costly. This is most likely not the case at Skavanger School as it is a quite densely populated area, but for schools in less populated areas, this could be interesting to take into account.

The spot price is a significant factor affecting the cost of the scenarios. The results show that for the three different spot prices, there are three different scenarios that are the cheapest. If the spot price is low, the scenarios that are dependent on a large amount of electricity from the grid will have an advantage. This could mean that scenarios with a low self sufficiency are more economically viable in a low spot price environment, as they import a large amount of energy. The scenarios that sell a large amount of energy to the grid, will have low revenue as spot prices are low.

When the spot price increases, certain scenarios become more economically viable. With the medium spot price, scenario Hydro-A, which has a battery, becomes cheaper than Hydro. This can be a result of the system being less dependent on the grid, and therefore importing less of the more expensive electricity. While this scenario is the least expensive, the difference in cost between Hydro and Hydro-A is less than 10 000 NOK, which is close to negligible when considering that this is a simulation over 25 years. However, this proves that there is a possibility that adding a battery to increase self sufficiency can be profitable.

High spot prices favour the scenarios with a high self sufficiency and a large amount of energy export. Scenario 1-A and 1-B are have a large reduction in total lifetime costs when moving from medium to high spot prices. This is because they are highly self sufficient, and therefore barely affected by the increased electricity bill, while getting an increased revenue from the export of energy. Scenario Original does not experience this reduction due to the low rate of self sufficiency, leading to a great portion of the energy demand being imported. On the other hand, scenario 1-A exports nearly as much as scenario Original.

Even though scenario Hydro and Hydro-A are the least expensive for the low and medium spot price, however the other scenarios show an interesting development with increasing spot prices. Scenario 1-A, 1-B, 2-A, and 2-B have a quite a large reduction in costs when the spot price increases. However, they have substantially larger costs related to installation and maintenance. 1-B and 2-B decreases substantially in regards to total lifetime cost, which is enough to be make these options cheaper than Hydro-A when considering high spot prices. The difference in prices are however less than with the low spot price. It can be argued that on a project of this size and the extent of assumptions in the calculations, there can be variances in the results that may account for this difference.

The general impact of a high spot price is a smaller variation in the total lifetime costs between the scenarios. Without taking into account scenario Original, the total costs are very close to each other. The least expensive option is scenario 2-B, with a 400 NOK advantage on scenario 1-B. These scenarios have such little difference between them that they can be assumed equally suitable. The similarity between both 1-A and 2-A, and 1-B and 2-B implies that the larger area of solar PV panels in scenario A is justified by the revenue from selling the excess electricity to the grid if the spot price is high enough.

5.4 Further Work

For the model in this thesis, the main focus areas are self sufficiency and lifetime cost with the FutureBuilt requirement as a foundation. Making a model that maximises the self sufficiency at each scenario have certain drawbacks. In the results, the electricity bill would be lower if more electricity was sold to the grid. For further work, it could be interesting to look at how another simulation model could focus on lowering the electricity bill, using the hydropower plant and the battery differently.

When making the model, simplifications and assumption were made as mentioned in Section 5.1. As modelling a battery was not the main focus of this bachelor thesis, a more general simulation of a battery was created. A consequence of this was that the battery was not used to minimise the electricity bill, but fill the power gap between demand and production when possible. If the morning peak or morning hours demanded more energy than produced, the battery would discharge to fill that gap. Often, the battery would then run out during the first hours of the day and leave no battery capacity for power gaps at the end of the day. To lower the electricity bill, the model could focus on reducing the power peaks during a day. Instead of only reducing the first peak completely, the model could try to import an smaller amount of electricity per hour. That would reduce the power peaks during a day and over a year, but could also increase the amount of energy imported. In addition, it would be interesting to combine that with the possibility of lowering the highest import peaks by changing the slope and azimuth of the solar PV panels to match the consumption profile.

It is worth considering how this thesis' definition of self sufficiency impacts the performance of the different scenarios. Due to the energy from the hydropower plant only covering energy consumption and charging the battery, any scenario including the hydropower plant will have a self sufficiency of at least 90.28 %. While this could indicate that a hydropower plant is good choice for a self sufficient energy system, it could also indicate that self sufficiency should be defined differently. The hydropower plant has no problem covering the energy demand during hours the school is closed like nights, weekends and during the summer holiday. This results in a high value for self sufficiency for all scenarios with hydropower, as the demand is covered for large periods of both day and night. Therefore, redefining self sufficiency to only look at the hours when the school is used (08:00-16:00) could be an option. Doing this would make self sufficiency focus on the hours where hydropower is unable to cover the energy demand by it self. However, even though this could give clearer overview of which scenario that is the most self sufficient in that time period, this would exclude many hours of the year and could result in losing sight of the bigger picture.

The results point towards the hydropower plant being the main driver for a favourable energy system, as specified in the thesis statement. Further work into scenarios with less solar PV panels and battery capacity may be beneficial in terms of finding the most favourable combination of high self sufficiency and low lifetime cost.

6 Conclusion

Analysing the results for this thesis, they indicate that the hydropower plant is a major source of self sufficiency for the proposed energy system. By itself, the hydropower plant can provide 90.28 % self sufficiency, but a significant amount of energy still has to be imported from the grid. The reason is that during the first hours of the day, the demand exceeds the production capabilities of the hydropower plant. Including a 150 kWh battery can help mitigate this problem, by increasing the self sufficiency to 98.38 %, while lowering total lifetime cost. A scenario such as this, represented as Hydro-A, does not produce enough energy to meet the requirements of the FutureBuilt standard. However, there is a adequate amount of water stored in the reservoir to alleviate this problem if more of the stored water is used for production and selling of electricity.

The results of the Original scenario, which only uses solar PV panels, suggest it performs poorly in regards to self sufficiency compared to the other scenarios. By combining hydropower, solar PV and batteries, the self sufficiency reaches 97-99 %. When looking at the lifetime costs over 25 years, scenario 2-B stands out with the lowest lifetime cost after Hydro and Hydro-A, while still reaching almost 98 % self sufficiency.

Predicting the future of electricity prices is difficult and because of this, all scenarios were compared to each other with high, medium and low spot prices. While looking at the different spot prices, scenario Hydro-A stood out as one of the cheapest scenarios in all cases. The highest spot prices makes scenario 1-B and 2-B cheapest, costing approximately the same as Hydro-A which was only 6 900 NOK higher in terms of lifetime cost. The scenarios that are affected the most in regards to lifetime costs when changing the spot prices, are 1-A and 1-B. They start out being more expensive with low spot prices, to becoming more competitive with high spot prices. Scenario 2-A and 2-B change to a lower extent, while Hydro and Hydro-A have close to the same lifetime cost for all three spot prices. This, as well as the low amount of variables in this scenario, makes Hydro-A the easiest to predict in terms of lifetime costs.

The results show that the simulation outcome depends strongly on how the the electricity prices develop in the future, in addition to changes in rules and regulations. By improving the simulation model to cut power peaks, the electricity bill could be reduced and it could be clearer which scenario is more favourable. In addition to this, the timing of when the costs are paid can be a factor to consider, as the options with solar PV panels increase the initial investment cost, but has a lower yearly cost.

To sum up, the cheapest scenario in terms of lifetime cost for all three spot prices that also has a high self sufficiency is Hydro-A. However, if the high spot price is assumed, 2-B is a better alternative, but only by a small margin. In addition to this, if the electricity bill is restructured to make high power peaks more expensive, 2-B may be even more favourable as the production and self sufficiency is higher than in the Hydro scenarios, while having a high export. The energy system for Skavanger School could be further optimised by looking at Hydro scenarios with a lower battery capacity, or an option similar to 2-B, but with less solar PV panels.

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A Energy Report from Rambøll

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SKAVANGER SKOLE
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Oppdragsnavn:	Skavanger Skole
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Godkjent av	Simen Tovmo
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INNHOLDSFORTEGNELSE

1. INNLEDNING

Rambøll Norge AS er engasjert av Veidekke til bygningsfysisk prosjektering og utføre energiberegninger for prosjektet Skavanger skole. Denne rapporten omfatter energikonseptet for dette prosjektet. Formålet med rapporten er å synliggjøre hvordan energikravene i «Forskrift om teknisk krav til byggverk» – TEK17 § 14 kan ivaretas, og det evalueres mot energikrav i teknisk forskrift gjeldende fra 1. januar 2016. I tillegg har byggherre satt som krav at bygget skal ivareta krav til passivhus iht. NS 3701:2012 og plusshus iht. FutureBuilt sin definisjon revidert desember 2018.

1.1 Beskrivelse av bygningskategori og beregning

Bygget er vurdert under bygningskategoriene «skolebygning» og standardiserte inputdata for beregningene stammer fra NS 3031:2014.

Ved utarbeidelse av energirapporten er det utført energiberegninger validert i det dynamiske beregningsprogrammet SIMIEN 6.013. Beregninger er utført med soneinndeling av skolen i tre deler. En sone for fløyen med klasserom, en sone for fløyen med spesialrom og kontorer og en sone for fellesarealene og amfiet. For beregning av arealer er det benyttet regler gitt for arealberegning iht. NS 3940:2012.

Oslo er valgt som klimasted for evaluering mot forskriftskrav i TEK, mens Kongsberg er valgt som klimasted for evaluering mot passivhuskrav og plusshus. Det benyttes standardiserte inndata for internlaster og driftstider, hentet fra NS 3031:2014 og NS 3701:2012. Dette gjør at beregningene for evaluering mot offentlige krav ikke vil være representative for bygningens *faktiske* energibruk/-behov. Beregning mot plusshus vil angi bygningens faktiske energibruk med de forutsetningene som legges til grunn.

1.2 Om prosjektet

Skavanger skole er en barneskole over to etasjer lokalisert i Kongsberg. Bygget inkluderer kontorlokaler for ansatte samt en kantine med et amfi for opptredener. Hovedbæresystem til bygget utføres i massivtre.

Prosjektet skal tilfredsstille krav fra Forskrift om tekniske krav til byggverk (TEK17), passivhus iht. NS 3701:2012 og plusshus etter definisjonen fra FutureBuilt.

Adresse: Dyrgravveien 5, 3617 Kongsberg
Gnr./Bnr.

2. ENERGIBEREGNING

2.1 Krav til energi iht. TEK17

For evaluering mot TEK 17 er det i energiberegningen brukt inputverdier fra NS 3031:2014

§14-2 Krav til energieffektivitet
Iht. TEK 17 skal bygninger "*prosjekteres og utføres slik at det tilrettelegges for forsvarlig energibruk*". For å tilfredsstille kravet om energieffektivitet (§14-2) må det teoretiske totale netto energibehovet for bygningene ikke overstige energirammen oppgitt i §14-2 (1). Bygningskategori skolebygning må tilfredsstille kravet til totalt netto energibehov på 110 kWh/m^2 oppvarmet BRA per år.

Iht. §14-2 (6) må yrkesbygninger og boligblokk med sentralt varmeanlegg være utstyrt med formålsdelte energimålere for oppvarming og tappevann. Dette kravet må ivaretas av RIV.

§14-3 Minimumskrav til energieffektivitet
Bygget må tilfredsstille minimumskravene beskrevet i §14-3 (1). Disse kravene sikrer akseptable kvalitet på enkeltkomponenter, samt bygningskroppene. Gjeldende minimumskrav er beskrevet i Tabell 1.

Tabell 1 - Minimumskrav.

U-verdi yttervegg [W/(m^{2}K)]	**U-verdi tak** [W/(m^{2}K)]	**U-verdi gulv på grunn og mot det fri** [W/(m^{2}K)]	**U-verdi vindu og dør, inkludert karm/ramme** [W/(m^{2}K)]	**Lekkasjetall ved 50 Pa trykkforskjell** [luftveksling pr. time]
≤ 0,22	≤ 0,18	≤ 0,18	≤ 1,2	≤ 1,5

I tillegg skal rør, utstyr og kanaler knyttet til bygningens varme- og distribusjonssystem iht. §14-3 (2) isoleres for å hindre varmetap. Dette kravet må ivaretas av RIV.

§14-4 Krav til løsninger for energiforsyning
§14-4 stiller følgende krav til energiforsyning:

(1) Det er ikke tillatt å installere varmeinstallasjon for fossilt brensel
(2) Bygning over 1000 m^2 oppvarmet BRA skal
   a. Ha energifleksible varmesystemer, og
   b. Tilrettelegges for bruk av lavtemperatur varmeløsning

§14-4 vurderes ikke videre i denne rapporten og RIV må dokumentere at krav i §14-4 er ivaretatt.

2.2 Krav til passivhusstandard iht. NS3701:2012

Bygget skal tilfredsstille passivhusstandard i henhold til NS 3701:2012 «*Kriterier for passivhus og lavenergibygninger-Yrkesbygninger*».

I likhet med evaluering mot TEK17 settes det også krav til energibehov til oppvarming og kjøling, samt til varmetapstall for transmisjon- og infiltrasjonstap, se Tabell 2. I motsetning til ved evaluering mot TEK17 tas det nå hensyn til lokalt klima når det settes krav til energibehov. Byggets oppvarmede BRA vil påvirke kravet til varmetapstall.

Tabell 2. Krav til passivhus iht. NS 3701:2012.

Bygningskategori	Skolebygning
Varmetapstall for transmisjons- og infiltrasjonstap	0,40 W/m^{2}K

Høyeste beregnede netto spesifikt energibehov for oppvarming	25,7 kWh/m²
Høyeste beregnede netto spesifikt energibehov til kjøling	5,4 kWh/m²
Krav til høyeste beregnede netto spesifikt energibehov til belysning	4,5 W/m²

I tillegg til kravene i Tabell 2 er det satt minstekrav til bygningsdeler, komponenter og tekniske installasjoner og lekkasjetall iht. kapittel 5 i NS 3701:2012, se Tabell 3.

Tabell 3. Minstekrav til bygningsdeler, komponenter og lekkasjetall for passivhus.

Egenskap		Passivhus
U-verdi vindu og dør		≤ 0,80 W/m²K
Normalisert kuldebroverdi		≤ 0,03 W/m²K
Årsgjennomsnittlig temperaturvirkningsgrad for varmegjenvinner		≥ 80 %
SFP-faktor ventilasjonsanlegg		≤ 1,5 kW/m³s
Lekkasjetall ved 50 Pa, n_{50}		≤ 0,6 h^{-1}
Belysning	Dynamisk dagslys- og konstantlysstyring	Minst 60 % av installert effekt til belysning er underlagt styringssystemet
	Dynamisk behovsstyring ved tilstedeværelse	Minst en styringssone per rom eller en styringssone per 30 m² i større rom

2.3 Plusshusdefinisjon fra FutureBuilt

Futurebuilt plusshus defineres på følgende måte iht. revidert notat fra FutureBuilt desember 2018:

«Energibruk relatert til drift av bygningen skal over året minst kompenseres gjennom produksjon av fornybar energi. For å regnes som plusshus, må det produseres overskuddsenergi på 2 kWh/m² BRA pr år».

Enhet for energibruk- og produksjon regnes i vektet levert energi i kWh/år, og energibruk til drift omfatter alle energiposter gitt i NS 3031:2014.

Fornybar elektrisitet skal produseres lokalt og være integrert i bygningsmassen eller på eiendommen. Fornybar elektrisitet som er produsert på tomta og som leveres inn på nettet, kommer til fratrekk i energiregnskapet med samme verdi som import av elektrisitet fra nettet.

Netto energibehov og levert energi skal beregnes og dokumenteres iht. NS 3031:2014 og NS 3701:2012. Energiberegningen skal gjøres med utgangspunkt i statistiske klimadata for stedet eller nærmeste målestasjon for et normalår. Klimadata skal dokumenters med kilde.

Det skal benyttes standardiserte driftstider som gitt i NS 3031:2014. Ved beregning av netto energibehov skal det benyttes reelle prosjekterte ventilasjonsluftmengder dimensjonert ut ifra materialbelastninger og personbelastninger. For utstyr og varmt tappevann benyttes det i beregningen normerte verdier iht. NS 3701:2012, men endelig energiregnskap korrigeres med faktisk bruk. Alle inndata til energiberegningen skal dokumenteres, og inndatafiler samt resultatfiler skal være en del av leveransen.

Det er krav til måling og etterprøving av energibruken til drift av byggene. Bygget må tetthetsprøves og termografers for å bekrefte beregningsforutsetningene mht. luftlekkasjer og varmeisolering av klimaskall.

3. GRUNNLAG FOR BEREGNING

Inndata
Beregninger og simuleringer er utført i henhold til bygningskategori skolebygning. For evaluering mot TEK17, er standardverdier hentet fra tillegg A og B i NS 3031:2014, mens det for evaluering mot passivhuskrav er standardverdier hentet fra NS 3031:2014/NS 3701:2012. Alle lengder og arealer er oppmålt fra arkitektens tegninger datert 20.12.2019.

Forutsatte varmegjennomgangskoeffisienter (U-verdier) for de forskjellige bygningselementene er presentert i Tabell 4, dimensjonerende varmekonduktivitet betegnes som "λ_d":

Tabell 4 Varmegjennomgangskoeffisienter.

Bygningskomponent	U-verdi [W/m²K]	Oppbygging konstruksjon
Oppvarmet areal		
Yttervegg massivtre	0,17	120mm massivtrevegg, 250 mm REDair, λ_d = 0,033 W/mK
Yttervegg teknisk rom	0,17	120mm massivtrevegg, 250 mm REDair, λ_d = 0,033 W/mK
Tak	0,09	100mm massivtre og 400mm isolasjon, λ_D = 0,039 W/mK
Gulv mot fri (inngang)	0,13	300mm isolasjon, bjelker 300x48, λ_D = 0,035 W/mK
Gulv på grunn	0,11 (0,08*)	300 mm kontinuerlig isolasjon λ_D = 0,035 W/mK
Vinduer/dører, 3-lags	0,70	Må bekreftes av vindusleverandør
Vinduer, 4-lags	0,40	Glassfasader atrium/fellesareal øst- og vestfasade. Må bekreftes av vindusleverandør
Andre verdier		
Normalisert kuldebroverdi [W/m²K]	0,02	Anslått kuldebroverdi basert på bæresystem med massivtre. Vil dokumenteres når detaljer er tilgjengelige.
Lekkasjetall, n_{50} [h^{-1}]	0,3	Forutsatt lekkasjetall. Må bekreftes oppnåelig av Veidekke. Trykktest gjennomføres i utførelsesfasen iht. NS-EN ISO 9972:2015 for dokumentasjon på oppfyllelse av konseptkrav.

*Ekvivalent verdi som inkluderer varmemotstand til grunnen

Ventilasjon
For evaluering er det forutsatt balansert ventilasjon med VAV. For ventilasjon og oppvarming benyttes normative verdier for driftstiden iht. NS 3031/NS3701 for evaluering mot krav i TEK17 og passivhus. For evaluering mot plusshus er det forutsatt at ventilasjonsanlegg skrues av utenfor driftstid.

Det er forutsatt en setpunkt-temperatur i driftstiden på 21^{0}C og 19 ^{0}C utenfor driftstid for oppvarmingsanlegget.

Tabell 5 viser foreløpige inndata for ventilasjonsaggregatet benyttet i energiberegningen. Forutsatte luftmengder, varmegjennvinning og SFP-faktor må bekreftes av RIV.

Tabell 5 Ventilasjoninndata

Ventilasjonsdata			Verdi	Referanse
Varmegjenvinner [%]			85	Må bekreftes av RIV
SFP [kW/m³/s]	**Klasseromsfløy**	**I driftstid**	1,25	Må bekreftes av RIV
		Utenfor driftstid	1,2	Må bekreftes av RIV
	Spesialundervisning og lærer	**I driftstid**	1,35	Må bekreftes av RIV
		Utenfor driftstid	1,2	Må bekreftes av RIV
	Fellesareal	**I driftstid**	0,9	Må bekreftes av RIV
		Utenfor driftstid	0,9	Må bekreftes av RIV
Luftmengder [m³/hm²]	**Klasseromsfløy**	**Maks i drift**	12,83	Må bekreftes av RIV
		Min. i drift	8	Må bekreftes av RIV
		Utenfor drift	2/0*	Forutsetter avslått utenfor driftstid for plusshus. Må bekreftes av BH
	Spesialundervisning og lærer	**Maks i drift**	8,72	Må bekreftes av RIV
		Min. i drift	8	Må bekreftes av RIV
		Utenfor drift	2/0*	Forutsetter avslått utenfor driftstid for plusshus. Må bekreftes av BH
	Fellesareal	**Maks i drift**	11,59	Må bekreftes av RIV
		Min. i drift	8	Må bekreftes av RIV
		Utenfor drift	2/0*	Forutsetter avslått utenfor driftstid for plusshus. Må bekreftes av BH

* For vurdering mot plusshus er det forutsatt at ventilasjonsanlegg er avslått utenfor driftstid.

Energiforsyning

Tabell 6 viser forutsatt energiforsyning for bygget.

Tabell 6 Energiforsyning, antatt fordeling

	Varmepumpe	EL
Romoppvarming	90 %	10 %
Oppvarming av tappevann	50 %	50 %
Varmebatteri ventilasjon	90 %	10 %
Kjølebatteri ventilasjon	100 %	-
Lokalkjøling	-	-
El. spesifikt energibehov	-	100 %

Det legges til grunn en produksjonsvirkningsgrad på 3,8 for bergvarmepumpen og vannbåren golvvarme med godt isolerte rør og lav temperatur. Dette må bekreftes av RIV.

Internlaster og driftstid

Ved evaluering mot TEK17 benyttes normative verdier gitt av NS 3031:2014 for driftstid, effekt og varmetilskudd fra belysning, teknisk utstyr, tappevann og personer. For beregning mot passivhuskrav og plusshus benyttes verdier angitt i Tabell 7 og Tabell 8.

Tabell 7 Internlaster

Internlaster [W/m²]	Verdi	Referanse
Belysning	4,5	Må dokumenteres/bekreftes av RIE. Iht. NS 3701, tabell 8
Teknisk utstyr	4	Iht. NS 3701, tabell A.3
Tappevann	1,9	Iht. NS 3031, tabell A.1
Varmetilskudd personer	12	Iht. NS3031, tabell A.2/NS3701, tabell A.3

Tabell 8 Driftstider

	Driftstid [timer/døgn/uker]	Referanse
Oppvarming, belysning og utstyr	10/5/44	Iht. NS 3031, tabell A.3
Ventilasjon	10/5/44	Iht. NS 3031, tabell A.3
Personer	10/5/44	Iht. NS 3031, tabell A.3

Solskjerming

Det er forutsatt solskjerming på vinduer i energiberegning, øst-, sør- og vestfasade. Glass er forutsatt med en konstant solfaktor på 0,51, mens med utvendig solskjerming aktivert er det forutsatt en solfaktor på 0,06 (utvendig screen).

4. RESULTATER

4.1 Evaluering mot forskriftskrav iht. TEK17

Resultatene i tabellene under er hentet fra energiberegningen i SIMIEN. Grønn farge betyr at alt er i henhold til kravene i TEK17, rød farge tilsier at enkeltkravet ikke tilfredsstilles.

For å evaluere prosjektet mot forskriftskrav i TEK17 er det utført en energirammeberegning i SIMIEN for prosjektet. Iht. energirammekrav i TEK17 skal maksimum energibehov ikke overstige 110,0 kWh/m^2 årlig for skolebygning.

RIV må dokumentere at:

- §14-2 (6) kravet om formålsdelte energimålere er oppfylt.
- §14-3 (2) rør, utstyr og kanaler knyttet til bygningens varme- og distribusjonssystem isoleres for å hindre varmetap.
- §14-4 Krav til løsninger for energiforsyning er ivaretatt.

Våre beregninger gir teoretisk beregnet totalt netto energibehov på 69,9 kWh/m^2 og kravet i TEK17 §14-2 (1) er dermed innfridd, se Figur 1. Figur 2 og Figur 3 viser at tiltaket tilfredsstiller minimumskravene gitt i §14-3 og krav til løsninger for energiforsyning gitt i §14-4 (1).

Evaluering mot forskriftskrav ved bruk av SIMIEN viser at bygget oppfyller energirammekravet og minstekrav. Dermed vil tiltaket totalt sett tilfredsstille kravene i TEK 17 mht. energieffektivitet, se Figur 4.

Energiramme (§14-2 (1), samlet netto energibehov)	
Beskrivelse	Verdi
1a Beregnet energibehov romoppvarming	8,8 kWh/m²
1b Beregnet energibehov ventilasjonsvarme (varmebatterier)	7,8 kWh/m²
2 Beregnet energibehov varmtvann (tappevann)	10,1 kWh/m²
3a Beregnet energibehov vifter	12,5 kWh/m²
3b Beregnet energibehov pumper	2,1 kWh/m²
4 Beregnet energibehov belysning	9,9 kWh/m²
5 Beregnet energibehov teknisk utstyr	13,3 kWh/m²
6a Beregnet energibehov romkjøling	0,0 kWh/m²
6b Beregnet energibehov ventilasjonskjøling (kjølebatterier)	5,4 kWh/m²
Totalt beregnet energibehov	69,9 kWh/m²
Forskriftskrav netto energibehov	110,0 kWh/m²

Figur 1 Evaluering mot energirammekrav i TEK17 §14-2 (1).

Minstekrav (§14-3)		
Beskrivelse	Verdi	Krav
U-verdi yttervegger [W/m²K]	0,17	0,22
U-verdi tak [W/m²K]	0,09	0,18
U-verdi gulv mot grunn og mot det fri [W/m²K]	0,08	0,18
U-verdi glass/vinduer/dører [W/m²K]	0,63	1,20
Lekkasjetall (lufttetthet ved 50 Pa trykkforskjell) [luftvekslinger pr time]	0,30	1,50

Figur 2 Evaluering mot minstekrav i TEK17 §14-3.

Energiforsyning (§14-4 (1))	
Beskrivelse	Verdi
Bruker fossilt brensel til oppvarming	Nei

Figur 3 Evaluering mot energiforsyning i TEK17 §14-4 (1)

Resultater av evalueringen	
Evaluering av	Beskrivelse
Energiramme	Bygningen tilfredsstiller energirammen ihht. §14-2 (1)
Minstekrav	Bygningen tilfredstiller minstekravene i §14-3
Luftmengder ventilasjon	Luftmengdene tilfredsstiller minstekrav gitt i NS3031:2014 (tabell A.6)
Energiforsyning	Fossilt brensel benyttes ikke i oppvarmingsanlegget (§14-4)
Samlet evaluering	Bygningen tilfredsstiller byggeforskriftenes energikrav

Figur 4 Oppsummering av evaluering mot energikrav i TEK17.

Iht. energikrav skal det for yrkesbygg også beregnes energibudsjett med reelle verdier, i tillegg til beregning med normerte verdier. Målet er å gi byggeier og bruker et anslag for forventet energibruk. Energibudsjettet skal beregnes iht. NS 3031:2014, men med spesifikke verdier som gjelder for den konkrete bygningen. Som minimum benyttes reelle verdier for:

- Lokale klimadata
- Skjerming av bygningen
- Innetemperatur
- Driftstider
- Ventilasjonsluftmengder i og utenfor driftstid
- Varmetilskudd fra belysning, utstyr og personer
- Energibehov for varmt tappevann
- Kjøling

Foreløpig energibudsjett med standardiserte verdier, men der lokalt klima for Kongsberg er hensyntatt (Figur 5).

Energibudsjett reelle verdier (§14-2 (5))		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	30928 kWh	9,4 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	9937 kWh	3,0 kWh/m²
2 Varmtvann (tappevann)	33123 kWh	10,0 kWh/m²
3a Vifter	21492 kWh	6,5 kWh/m²
3b Pumper	5103 kWh	1,5 kWh/m²
4 Belysning	32680 kWh	9,9 kWh/m²
5 Teknisk utstyr	29052 kWh	8,8 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	7349 kWh	2,2 kWh/m²
Totalt netto energibehov, sum 1-6	169664 kWh	51,4 kWh/m²

Figur 5 Energibudsjett med reelle verdier iht. § 14-2 (5).

4.2 Evaluering mot passivhus iht. NS 3701:2012

Figur 6 og Figur 7 viser hhv. verifisering av krav til energiytelsen og beregnet varmetapsbudsjett.

Energiytelse		
Beskrivelse	Verdi	Krav
Netto oppvarmingsbehov	23,0 kWh/m²	25,7 kWh/m²
Netto kjølebehov	3,5 kWh/m²	5,4 kWh/m²
Gjennomsnittlig effektbehov belysning	4,5 W/m²	4,5 W/m²

Figur 6 Verifisering av krav til energiytelse.

Høyeste varmetapstall for transmisjons- og infiltrasjonstap er 25,7 W/m²K for skolebygning der oppvarmet bruksareal er større eller lik 1000 m² som skal utføres som passivhus. Som vi ser av Figur 7 er det beregnede varmetapstallet for dette bygget på totalt 23,0 W/m²K, og kravet er dermed innfridd.

Varmetapsbudsjett	
Beskrivelse	Verdi
Varmetapstall yttervegger	0,09
Varmetapstall tak	0,05
Varmetapstall gulv på grunn/mot det fri	0,04
Varmetapstall glass/vinduer/dører	0,08
Varmetapstall kuldebroer	0,02
Varmetapstall infiltrasjon	0,03
Totalt varmetapstall	0,30
Krav varmetapstall	0,40

Figur 7 Totalt beregnet varmetapstall for bygget.

NS 3701:2012 stiller også minimumskrav til komponenter og tekniske løsninger. Figur 8 viser at de prosjekterte verdiene tilfredsstiller disse minstekravene.

Minstekrav enkeltkomponenter		
Beskrivelse	Verdi	Krav
U-verdi glass/vinduer/dører [W/m²K]	0,63	0,80
Normalisert kuldebroverdi [W/m²K]	0,02	0,03
Årsmidlere temperaturvirkningsgrad varmegjenvinner ventilasjon [%]	85	80
Spesifikk vifteeffekt (SFP) [kW/m³/s]:	1,22	1,50
Lekkasjetall (lufttetthet ved 50 Pa trykkforskjell) [luftvekslinger pr time]	0,30	0,60

Figur 8 Dokumentasjon på oppfyllelse av minstekrav i NS 3701:2012.

I tillegg skal følgende minstekrav være oppfylt vedrørende belysning:

Krav til energibehov belysning
Minst 60 % av installert effekt skal være underlagt dynamisk dagslys- og konstantlysstyring.
Alle rom skal ha dynamisk behovsstyring ved tilstedeværelse. Store rom skal ha minst en styringssone per 30 m2.
Energibehovet skal dokumenteres etter NS-EN 15193 basert på prosjektert eller installert effekt og styringssystemets innvirkning på energibehovet.
All belysning skal minst tilfredsstille kvalitetskravene for belysning gitt i NS-EN 12464-1.

Figur 9 Krav til energibehov belysning

Evaluering mot passivhuskrav ved bruk av SIMIEN viser at bygget tilfredsstiller kravene i NS 3701:2012.

Resultater av evalueringen	
Evaluering mot NS 3701	Beskrivelse
Varmetapsramme	Bygningen tilfredstiller kravet for varmetapstall
Energiytelse	Bygningen tilfredsstiller krav til energiytelse
Minstekrav	Bygningen tilfredsstiller minstekrav til enkeltkomponenter
Luftmengder ventilasjon	Luftmengdene tilfredsstiller minstekrav gitt i NS3701 (tabell A.2)
Samlet evaluering	Bygningen tilfredstiller alle krav til passivhus

Figur 10 Oppsummering av evaluering av energikrav i NS 3701:2012.

4.3 Evaluering mot FutureBuilts plusshusdefinisjon

Behov for produsert energi fra solceller iht. Futurebuilts definisjon når det forutsettes et areal på 3301 m^2 BRA er angitt i Tabell 9 og Tabell 10. For å oppnå FutureBuilts plusshusdefinisjon er man nødt til å produsere 134 266 kWh eller mer pr. år med de forutsetningene som er lagt til grunn.

Tabell 9 Beregnet energibehov og levert energi for Skavanger skole

Energipost	Netto energibehov [kWh]	Levert energi [kWh]
Romoppvarming	30 928	11 947
Ventilasjonsvarme	9 937	3 530
Varmtvann	33 123	20 919
Vifter	21 492	21 492
Pumper	5 103	5 103
Belysning	32 680	32 680
Teknisk utstyr	29 052	29 052
Romkjøling	0	0
Ventilasjonskjøling (kjølebatteri)	7 349	2 939
Totalt	169 664	127 664

Tabell 10 Nødvendig strømproduksjon

Beregnet levert energi [kWh]	127 664
Overskuddsenergi iht FutureBuilt (2 kWh/m^2 pr BRA) [kWh]	6 602
Nødvendig strømproduksjon [kWh]	134 266
Nødvendig areal solceller (antatt 140 kWh/m^2) [m^2]	959

5. OPPSUMMERING

Inndata som er lagt til grunn for våre beregninger konkluderer med at Skavanger skole oppfyller energikravene i TEK17 og passivhus iht. NS 3701. For å oppnå FutureBuilts plusshusdefinisjon må bygget produsere minimum 134 266 kWh strøm årlig.

Hvis forutsetningene for energiberegningene endres, må det gjennomføres en ny energiberegning for å dokumentere at de ulike energikravene er oppfylt.

6. SENTRALE INNDATA

Tabellen nedenfor er hentet fra NS 3031:2014, Tillegg J. Dette er et skjema som samler sentrale inndata for beregning av energibehov.

Tabell 11. Dokumentasjon av sentrale inndata for energiberegningen, TEK17.

Størrelser		Inndata	Dokumentasjon
Arealer [m^2]	Yttervegger	1 706	
	Tak	1 656	
	Gulv	1 656	
	Vinduer, dører, porter og glassfelt	407	
Oppvarmet del av BRA (A_{fl}) [m^2]		3 301	
Oppvarmet luftvolum (V) [m^3]		12 783	
U-verdi for bygningsdeler [W/(m^2·K)]	Yttervegger	0,17	Se oppbygging av konstruksjonsdeler i Tabell 4.
	Tak	0,09	
	Gulv	0,08	
	Vinduer/dører/porter/ glassfelt	0,63	
Arealandel for vinduer, dører og glassfelt (γ_{sol}) [%]		12,3	Beregnet av Rambøll
Normalisert kuldebroverdi (Ψ'') [W/(m^{2}K)]		0,02	Vil dokumenteres av Rambøll når detaljer er tilgjengelige
Normalisert varmekapasitet (C") [Wh/(m^2·K)]		56	
Lekkasjetall (n_{50}) [h^{-1}]		0,30	Trykktest gjennomføres i utførelsesfasen iht. NS-EN 9972:2015 for dokumentasjon på oppfyllelse av konseptkrav.
Temperaturvirkningsgrad (η_T) for varmegjenvinner [%]		85	
Estimert årsgjennomsnittlig temperaturvirkningsgrad for varmegjenvinner pga. frostsikring [%]		85	
Spesifikk vifteeffekt (*SFP*) relatert til luftmengder i driftstiden [kW/(m^3/s)]		1,22	
Spesifikk vifteeffekt (*SFP*) relatert til luftmengder utenfor driftstiden [kW/(m^3/s)]			
Gjennomsnittlig spesifikk ventilasjonsluftmengde i driftstiden ($\dot{V}_{on}/A_{fl}$) [m^3/(m^2·h)]		11,09	
Gjennomsnittlig spesifikk ventilasjonsluftmengde utenfor driftstiden ($\dot{V}_{red}/A_{fl}$) [m^3/(m^2·h)]		2,0	
Årsgjennomsnittlig systemvirkningsgrad/varmefaktor for oppvarmingssystemet [%]		2,14	
Installert effekt for romoppvarming og ventilasjonsvarme (varmebatteri) [W/m^2]		80	
Settpunkttemperatur for oppvarming [°C]		19,8	Iht. NS 3031 tillegg A, tab. A.3.
Årsgjennomsnittlig kjølefaktor for kjølesystemet [%]		2,50	

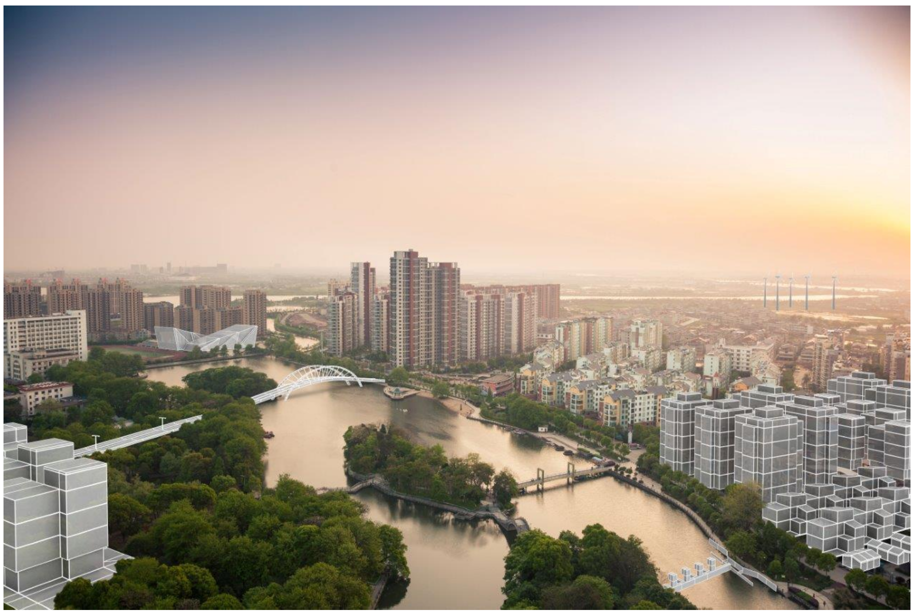
Størrelser	Inndata	Dokumentasjon
Settpunkt for kjøling [°C]	22,0	
Installert effekt for romkjøling og ventilasjonskjøling [W/m²]	30	
Spesifikk pumpeeffekt (*SPP*) [kW/(l·s)]	1,6	
Driftstid for; - ventilasjon, - oppvarming, - kjøling, - lys, - utstyr, - varmtvann og - personer	10/5/44	Iht. NS 3031 tillegg A, tab. A.3, for bygningskategori skolebygning. Dette er standardverdier som skal benyttes ved evaluering mot forskrift.
Spesifikt effektbehov for belysning i driftstiden [W/m²]	4,50	Iht. NS 3031 tillegg A, tab. A.1 og A.2, for bygningskategori skolebygning. Dette er standardverdier som skal benyttes ved evaluering mot forskrift.
Spesifikt varmetilskudd fra belysning i driftstiden (q''_{lys}) [W/m²]	4,50	
Spesifikt effektbehov for utstyr i driftstiden [W/m²]	6,0	
Spesifikt varmetilskudd fra utstyr i driftstiden (q''_{uts}) [W/m²]	6,0	
Spesifikt effektbehov for varmtvann i driftstiden (q''_{w}) [W/m²]	1,9	
Varmetilskudd fra varmtvann i driftstiden [W/m²]	0	
Varmetilskudd fra personer i driftstiden (q''_{pers}) [W/m²]	12,0	
Total solfaktor ($\bar{g}_t$) for vindu og solskjerming (N/Ø/S/V)	0,51 0,06	Solfaktor til glass Solfaktor til glass + solskjerming
Gjennomsnittlig karmfaktor (F_F)	0,2	
Solskjermingsfaktor pga. horisont, nærliggende bygninger, vegetasjon og eventuelle bygningsutspring	0,92/0,62/0,87/0,68	Det er lagt inn bygningsutspring

B Sweco's Report on Micro Hydropower

SWECO

RAPPORT

Muligheter for mikrovannkraft ved Skavanger skole



Kunde:	Kongsberg kommunale eiendom KF
Prosjekt:	Utredning for energilagring/produksjon mikrovannkraft og SaltX teknologi
Prosjektnummer:	10216192
Dokumentnummer:	1 Rev.: 1

SWECO

Sammendrag:

Rapporten omhandler muligheter for etablering av et mikrovannkraftverk tilknyttet Skavanger skole med vann fra Tangentjernet. Målet er å få til en produksjon som kan erstatte 300 m^2 solcelleareal, tilsvarende en produksjon på ca. 50 000 kWh/år. Skavanger skole er planlagt bygget etter FutureBuilts plusshus-definisjon, som her gir behov for en egenproduksjon av energi på 134 266 kWh/år.

I rapporten vurderes to alternative rørtraseer og tre ulike produksjonsscenarier. En rørtrasè fra Tangentjernet via Rundtjern og Futentass som i hovedsak følger Stollveien blir funnet å være det beste alternativt. Rørtraseen blir ca. 1300 meter lang med brutto fallhøyde 151 meter. Avhengig av driftsopplegg og overføring av vann fra Kunstbekken estimeres mikrovannkraftverket å kunne redusere underproduksjonen om vinteren med mellom 4 000 kWh og 35 000 kWh, og tilsvarende redusere overproduksjonen om sommeren med mellom 0 kWh og 31 500 kWh.

Økonomien i prosjektet vil være sterkt avhengig av mulighetene for samarbeid eller sambruk med Kongsberg kommune vann- og avløpsplaner for nytt reservevannanlegg. Ekskl. kostnader til grøfting og legging av rør estimeres kostnader til tekniske installasjoner kr 660 000 – kr 690 000. Kostnader til grøfting og legging av rør estimeres til et sted mellom kr 650 000 og kr 1 300 000.

Prosjektet ventes ikke å gi større utfordringer mht. regelverk, planer eller andre interesser. Det bør vurderes å inngå avtaler om bruk av vann med Kongsberg skisenter og Kongsberg kommune.

Rapporteringsstatus:

☒ Endelig
☐ Oversendelse for kommentar
☐ Utkast

Utarbeidet av: Pål Preede Revheim, Kari Haugan	**Sign.:**
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Revisjonshistorikk:

1	02.03.20	Mikrovannkraft Skavanger skole	PPR, KH	SE
Rev.	**Dato**	**Beskrivelse**	**Utarbeidet av**	**Kontrollert av**

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Innholdsfortegnelse

1 Innledning

I denne rapporten vurderes tekniske muligheter for bygging av et mikrovannkraftverk tilknyttet nye Skavanger skole i Kongsberg. Dette kapittelet tar for seg bakgrunnen for oppdraget og hvilken funksjon et mikrovannkraftverk har potensiale til å dekke.

1.1 Bakgrunn og forutsetninger

Kongsberg kommunestyre vedtok 12. september 2018 at det skal bygges ny skole på Skavanger med ferdigstillelse til skoleåret 2021/22. Skolen skal bygges som en fleksibel 1,5-parallell grunnskole for 1.-7. trinn for 275 elever, med mulighet for seinere utvidelse til en 2-parallell skole. Skavanger skole skal bygges i massivtre og som plusshus etter FutureBuilt-definisjonen. For å få til dette er det planlagt varmepumper fra energibrønner i fjell, et større solcelleanlegg og energilagring i form av termisk lagring i varmtvann og en mindre batteribank. Det vurderes også muligheter for sesonglagring av solenergi som varme-energi i saltkrystaller og et mikrovannkraftverk med vann fra Tangentjern. Denne rapporten omhandler tekniske muligheter for sistnevnte.

Rapporten tar utgangspunkt i et ønske om at mikrovannkraftverket skal erstatte ca. 300 m^2 solceller. Videre er det tatt utgangspunkt i at Kongsberg kommune ved Vann og avløp planlegger et nytt reservevannanlegg med tilførsel fra Tangentjernet via Rundtjern og Futentass. Det har ikke vært mulig å få ytterligere detaljer om disse planene da prosjektet først skal starte opp over sommeren. Kostnadene til rørtrasé (rør + grøfting) forventes å utgjøre en betydelig del av de samlede utgiftene til et mikrovannkraftverk. Det er derfor lagt stor vekt på å prøve å finne løsninger hvor det kan være mulig å kombinere mikrovannkraft med et nytt reservevannanlegg. Hvorvidt dette faktisk er gjennomførbart må imidlertid avklares når planleggingen av reservevannanlegget kommer i gang.

1.2 Energibehov

Rambøll har gjennomført energiberegninger og utarbeidet en energirapport for Skavanger skole. I denne er det beregnet energiforbruk, behov for tilført energi og behov for egenproduksjon av energi for at bygget skal ivareta TEK17, passivhusdefinisjonen i NS 3701:2012 og plusshus-definisjonen til FutureBuild (rev. Desember 2018). Rapporten konkluderer med at Skavanger skole, gitt forutsetningene som er lagt til grunn, oppfyller energikravene i TEK17 og kravene til plusshus etter NS 3701. For at Skavanger skole skal oppfylle kravene til plusshus etter FutureBuilt-definisjonen må skolen ha en årlig energiproduksjon på minimum 134 266 kWh.

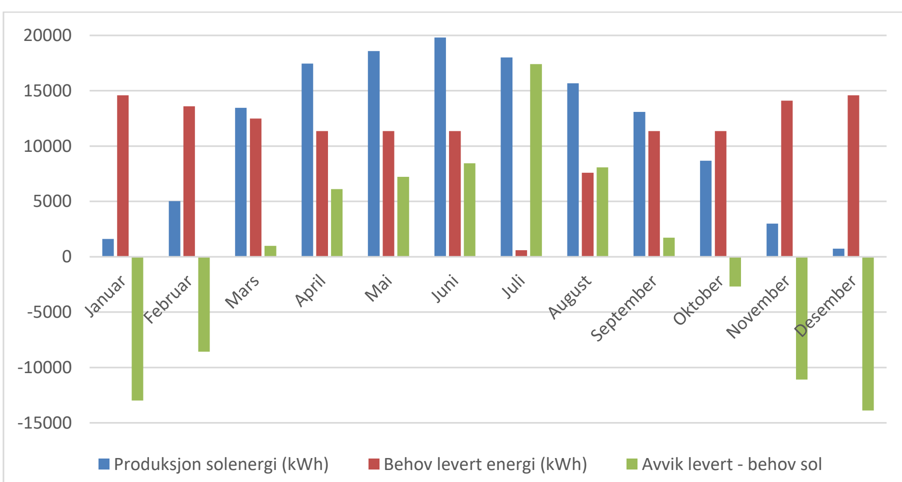
Tabell 1 – Energibehov for Skavanger skole (Kilde: Rambøll, Skavanger skole energirapport)

Energipost	Behov levert energi (kWh)
Romoppvarming	11 947
Ventilasjonsvarme	3 530
Varmtvann	20 919

Vifter	21 492
Pumper	5 103
Belysning	32 680
Teknisk utstyr	29 052
Romkjøling	0
Ventilasjonskjøling	2 939
Overskuddsenergi ihht. FutureBuilt (2 kWh/m^2 BRA)	6 602
Nødvendig energiproduksjon per år ved FutureBuilt	**134 266**

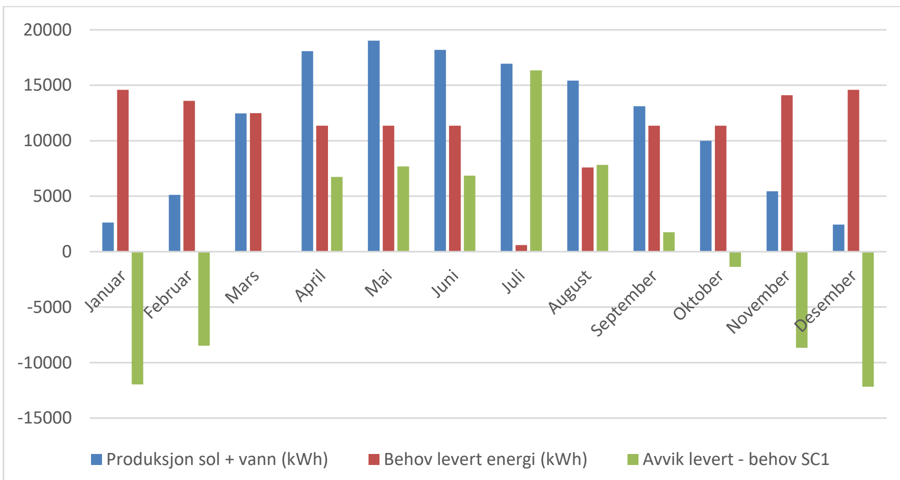
1.3 Lokal el-produksjon

Den mest nærliggende kilden til energiproduksjon for å oppfylle FutureBuilt-definisjonen er solceller. Solceller har falt kraftig i pris de siste årene, og er i dag en moden og velfungerende teknologi med lang levetid og lavt vedlikeholdsbehov. Årlig produksjon fra solceller i Kongsberg antas å ligge et sted mellom 140 – 170 kWh/m^2. Dette gir behov for et solcelleareal i området 790 – 960 m^2 for å dekke opp behovet på 134 266 kWh. I tillegg til dette kommer areal til adkomst, vedlikehold mm.



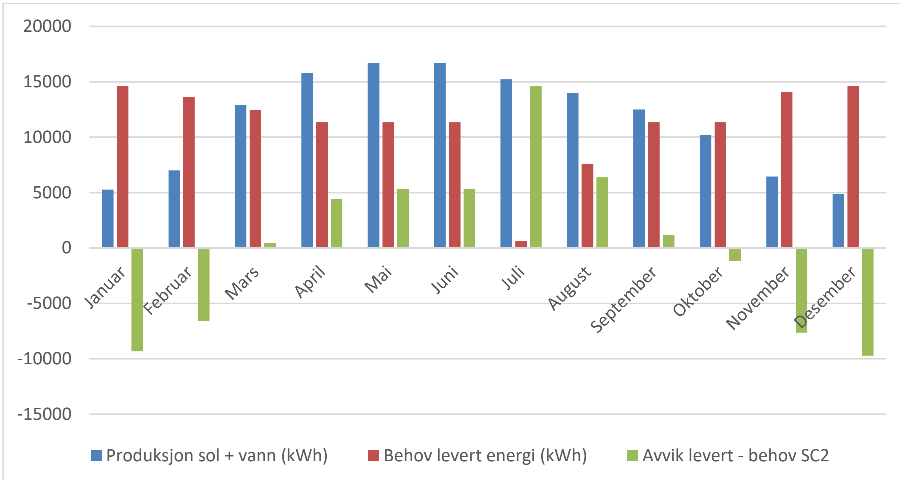
Figur 1 – Estimert produksjonsprofil fra solenergi (blå), estimert månedsbehov for tilført energi (rød) og avvik mellom behov og produksjon (grønn).

Figur 1 viser estimert produksjonsprofil for et solcelleanlegg dimensjonert etter behovet for energiproduksjon i FutureBuilt-definisjonen sammenstilt med estimert behov for levert energi og avvik mellom behov og produksjon. Figuren viser tydelig den største utfordringen ved å dekke behovet for egen energiproduksjon med solceller. Solenergiproduksjonen er stor om sommeren og liten om vinteren, mens behovet for tilført energi er lite om sommeren og stort om vinteren. Høst og vår er produksjon og behov i bedre balanse. Gjennom vintermånedene (oktober til februar) vil produksjonen av solenergi være ca. 46 000 kWh lavere enn behovet, mens den i sommermånedene (april til september) vil være cirka 47 000 kWh høyere enn behovet. Dette er en ubalanse som enten må dekkes gjennom lagring, annen energiproduksjon eller kjøp/salg fra nettet.



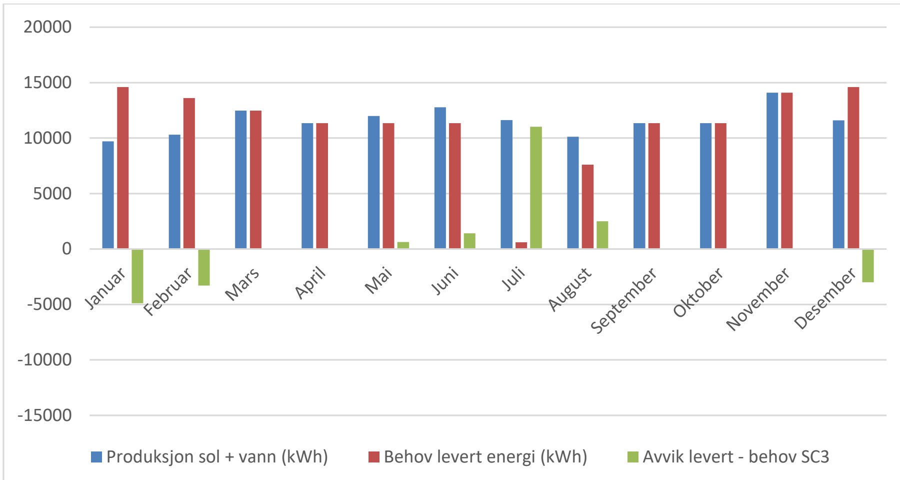
Figur 2 - Estimert produksjonsprofil fra sol + vann scenario 1 (blå), estimert månedsbehov for tilført energi (rød) og avvik mellom behov og produksjon (grønn). Mikrovannkraft utnytter tilsig til Tangentjernet alene.

En utbygging av mikrovannkraft ved Skavanger skole vil ha et to-delt mål – å redusere behovet for solcelleareal og å redusere vinter/sommer-ubalansen. I Figur 2 er deler av solenergien byttet ut med mikrovannkraft produsert fra det tilgjengelige tilsiget fra Tangentjernet alene (beskrevet som Scenario 1 i Kapittel 2.3). Dette gir en årsproduksjon på ca. 30 000 kWh, nok til å erstatte 160 – 170 m^2 solcelleareal. Underproduksjonen i vintermånedene vil være ca. 42 500 kWh (oktober til februar, en reduksjon på ca. 4 000 kWh sammenlignet med ren solenergi) og en overproduksjon i sommermånedene på ca. 47 000 kWh (april til september, på samme nivå som med ren solenergi).



Figur 3 – Estimert produksjonsprofil fra sol + vann scenario 2 (blå), estimert månedsbehov for tilført energi (rød) og avvik mellom behov og produksjon (grønn). Mikrovannkraft utnytter tilsig til Tangentjernet og Kunstbekken.

I Figur 3 er 50 000 kWh solenergi erstattet med mikrovannkraft. Mikrovannkraftverket kjøres som beskrevet i Scenario 2 i Kapittel 2.3. Dette reduserer behovet for solcelleareal med et sted mellom 300 m^2 og 350 m^2. Ved å ha en flat produksjonsprofil gjennom året vil et slik hybridanlegg ha en underproduksjon på ca. 33 000 kWh i vintermånedene (november til februar, en reduksjon på ca. 13 000 kWh sammenlignet med ren solenergi) og en overproduksjon i sommermånedene på ca. 36 000 kWh (april til august, ned 11 000 kWh sammenlignet med ren solenergi).



Figur 4 – Estimert produksjonsprofil fra sol + vann scenario 3 (blå), estimert månedsbehov for tilført energi (rød) og avvik mellom behov og produksjon (grønn). Mikrovannkraft begrenset til 50 000 kWh/år og tilgjengelig tilsig per måned, og regulert for å minimere sommer-vinter ubalanser.

Ved å utnytte fleksibilitetsmulighetene som ligger i vannkraften kan sesong-ubalansen reduseres ytterligere. I Figur 4 er det tatt utgangspunkt i realistisk mulig produksjon tilsvarende Scenario 3 i Kapittel 2.3 tilpasset de samme forutsetningene om reduksjon av solcelleareal og -produksjon som i Figur 3. Målet er å minimere ubalansene innenfor begrensningene gitt av de fysiske forutsetningene og den nødvendige energiproduksjonen i FutureBuilt-definisjonen. Ved å utnytte fleksibiliteten er det mulig å komme ned i en underproduksjon i vintermånedene på ca. 11 000 kWh (desember til februar, ned 35 000 kWh sammenlignet med ren solenergi) og en overproduksjon i sommermånedene på ca. 15 500 kWh (mai til august, ned ca. 31 500 kWh sammenlignet med ren solenergi). Overproduksjonen om sommeren er i all hovedsak forårsaket av svært lavt energibehov i sommerferien i juli.

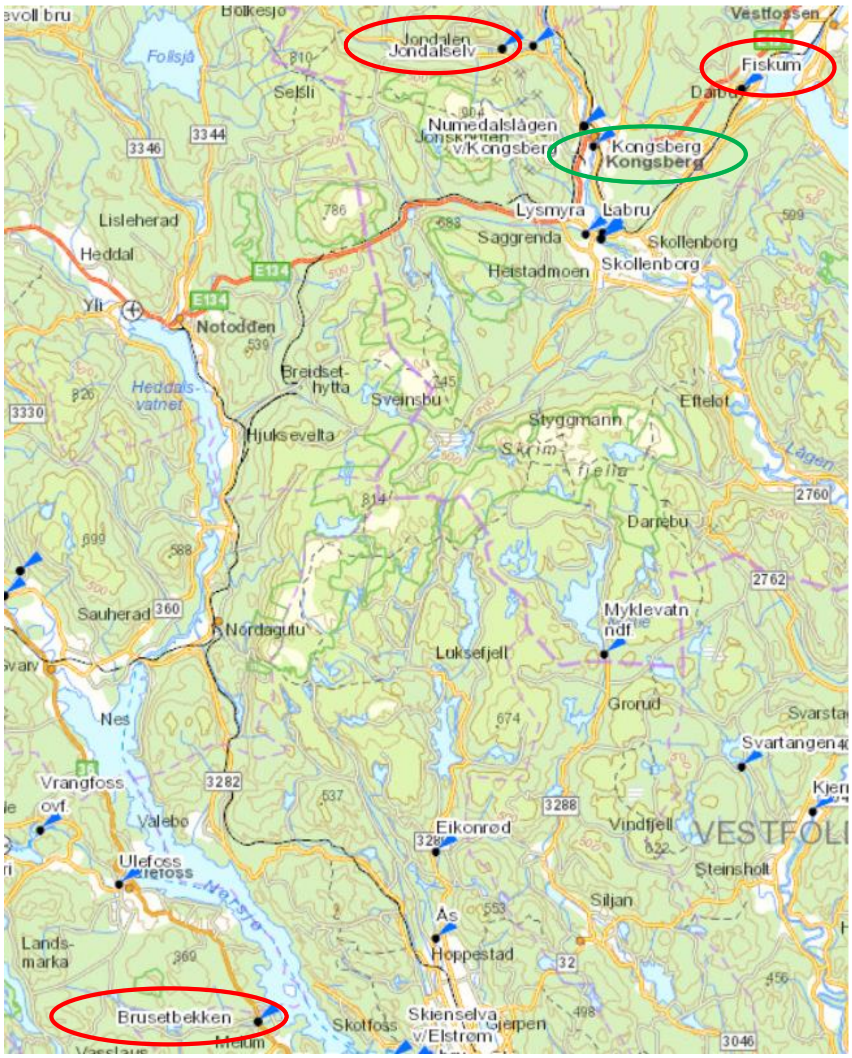
2 Mikrovannkraft

I dette kapittelet vurderes de naturgitte forutsetningene for mikrovannkraft ved Skavanger skole, og hvilke føringer disse gir for mulig produksjon og tekniske løsninger.

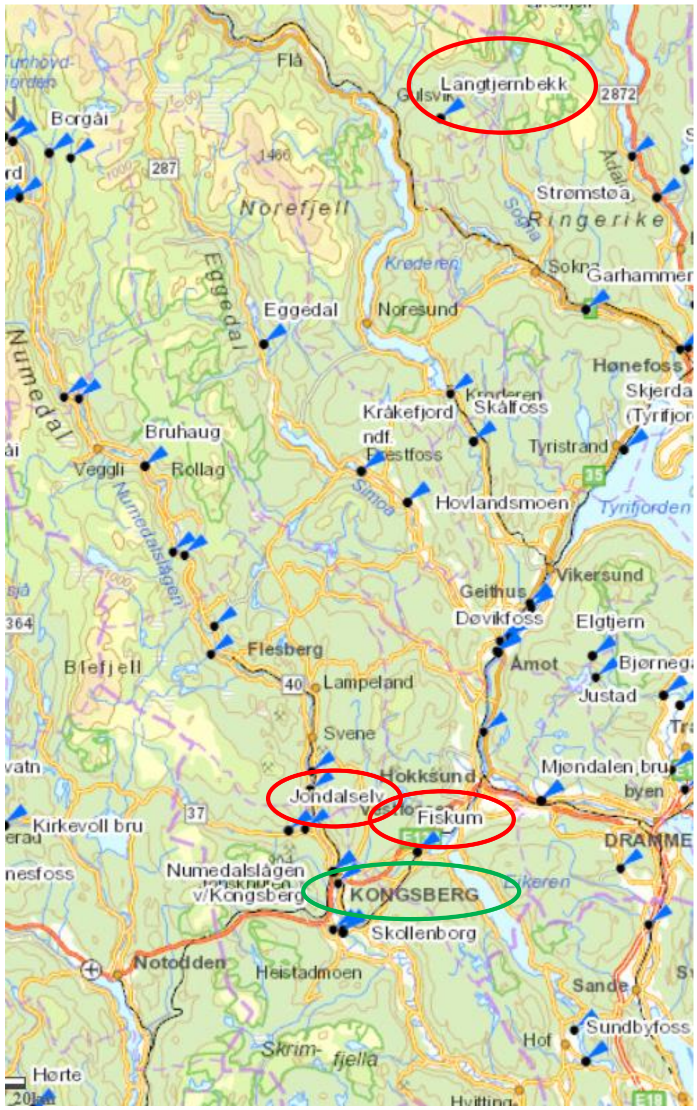
2.1 Hydrologi

Produksjonsestimater for et mulig mikrokraftverk ved Skavanger skole er utarbeidet fra areal- og avrenningsforhold hentet fra Nevina og vannføringstall fra HYDRA II. Øvrig informasjon om plassering, installasjon etc. er gjort på bakgrunn av informasjon fra Kongsberg kommunale eiendom KF ved Hallvard Benum og VTA for Kongsberg kommune Tor Arne Folserås.

For valg av målestasjon som underlag for vannføringsdata i produksjonsberegningen er det sett på flere relevante målestasjoner i området. Figur 5 og 6 viser en oversikt over aktuelle målestasjoner som er vurdert for prosjektet.



Figur 5 - Oversikt over vurderte målestasjoner i området, her vises Brusetbekken, Jondalselv og Fiskum.



Figur 6 - Oversikt over vurderte målestasjoner i området, her vises Jondalelv, Fiskum og Langtjernbekk.

Ut ifra nøkkeltallene for nedbørsfeltene listet i Tabell 2, er det tatt en vurdering i forhold til hvilken målestasjon som best representerer nedbørsfeltet til det fremtidige mikrokraftverkprosjektet i Skavanger. Forholdene som sammenlignes er i hovedsak middelvannføring, areal, maks og minimum høyde og forholdene mellom sjø, bre, skog og snaufjell.

Det er valgt å bruke NVEs vannmerke VM 12.188 Langtjernbekken, som er et uregulert felt, til videre vurdering av mikrovannkraftverket. Dette vannmerke er vurdert som et godt vannmerke, da det ligger ca. samme lengdegrad som Tangentjern og tillegg har middelvannføring og areal som er mest likt nedbørsfeltet til Tangentjern.

Naturlig har Tangentjern et relativt lite nedbørsfelt på 0.4 km^2, men det overføres vann fra Kunstbekken via en overføringstunnel. Forutsatt at overføringen til Kunstbekken opprettholdes så har nedslagsfeltet til Tangentjern er totalt areal på 2,87 km2. Sweco har ikke tilgang til offentlige dokumenter som beskriver overføringen, viser derfor til mail fra VTA for Kongsberg kommune Tor Arne Folserås (se vedlegg) for tall angående overføringen.

Tabell 2 - Nøkkeltall hydrologi

	Tangentjern	Tangentjern inkludert Kunstbekken	16.154 Brusetbekken	15.21 Jondalselv	12.193 Fiskum	12.188 Langtjernbekken
Middelvannføring (1961-1990) (l/s/km²)	19	19	9.4	22.9	17.8	19.7
Vassdragsnummer	015.D22	-	016.B4	015.DZ	012.AB3Z	012.CB5C
Klimaregion	Øst	-	Sør	Øst	Øst	Øst
Areal (km²)	0.4	2.87	7.5	127.6	50.8	4.9
Minimum høyde (moh)	326	-	64	228	80	514
Maksimum høyde (moh)	426	-	308	921	646	757
Bre (%)	0.0	-	0.0	0.0	0.0	0.0
Myr (%)	2.0	-	1.7	5.1	3.1	6.9
Sjø (%)	32.9	-	1.7	3.3	1.3	6.6
Skog (%)	65.4	-	90.5	77.2	88.4	86.4
Snaufjell (%)	0.0	-	0.0	9.4	0.0	0.0
Effektiv sjø (%)	32.2	-	0.4	0.3	0.1	4.7
Sommertemperatur (Mai-September) (°C)	11.4	-	12.7	9.7	11.8	9.1
Vintertemperatur (Oktober - April) (°C)	-2.1	-	-0.1	-3.3	-1.9	-4.5

For de fire målestasjonene er det gjort en vurdering av endring i vannføring for årene 1961-1990 mot de siste 30 år – 1989-2018. Er det store endringer her, må man ta hensyn til dette. Som det fremgår av Tabell 3 så er det store variasjoner mellom målestasjonene i endring i vannføring for de to periodene. Resultatene viser både økende og synkende middelavrenning. For valgt vannmerke er det registrert liten endring i middelavrenningen. Det er ut ifra dette vurdert at man ikke justerer for valgt vannmerke 12.188 Langtjernbekken, og bruker middelavrenning fra Nevina ved skalering av tilsigsdata fra vannmerke 12.188 Langtjernbekken.

Tabell 3 - Vurdering av endring i vannføring

Målestasjon	Middelvannføring 1961-1990 (l/s), Nevina	Middelvannføring 1989-2018 (l/s), Hydra II	% endring i vannføring
16.154 Brusetbekken	71	141	50 % økning
15.21 Jondalselv	2922	3200	10 % økning
12.193 Fiskum	904	822	10 % reduksjon
12.188 Langtjernbekken	96	97	0.6 % økning

2.2 Teknisk løsning

Mikrokraftverket vil utnytte fallet fra Tangentjern som tilsvarer 150 m brutto fall fra kote 330 ned til kote 180. Stasjonsbygget foreslås plassert på sørsiden av idrettsparken i tilknytning til eiendom 7716/1 eller 7716/6. Dette er en plassering som utnytter hele det potensielle fallet, men uten at rørtraseen er lengre enn nødvendig. Slik vil plasseringen være god både med tanke på produksjon og utbyggingskostnad.

Sweco har sett på to alternativer til rørtraseer (se Figur 7):

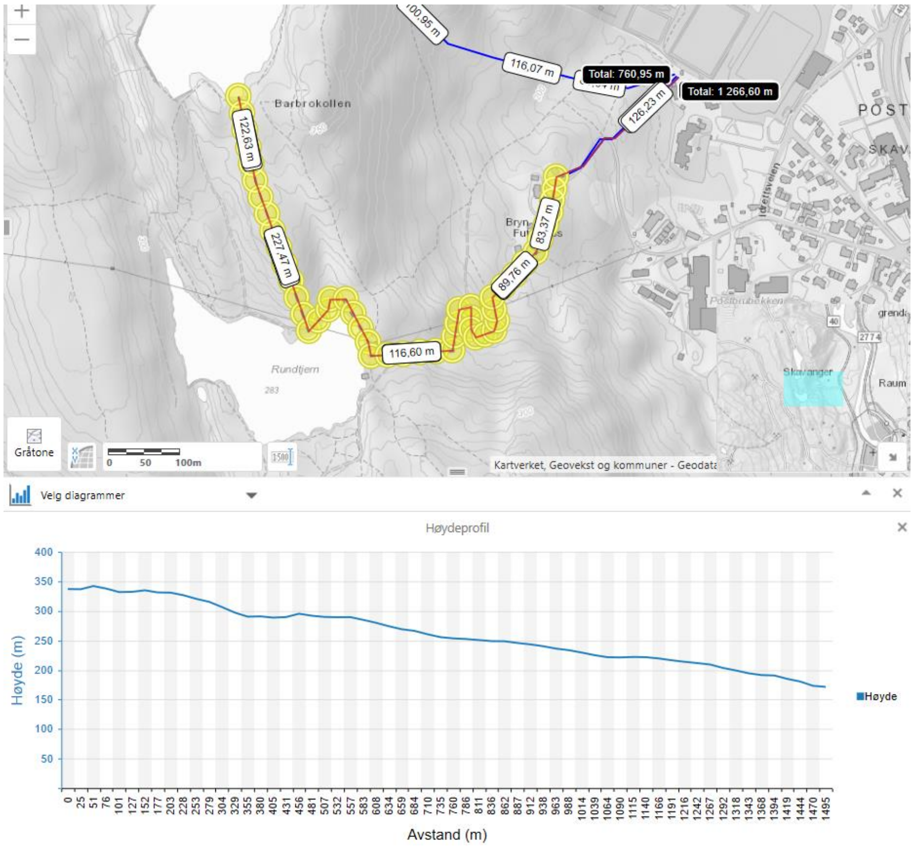
- **Traséalternativ 1** har uttak på østsiden av Tangentjernet og går korteste vei ned til Skavanger skole. Traseen går i all hovedsak i ikke-opparbeidet og til dels bratt terreng med tynt jorddekke. I dette alternativet vil rørtraseen bli 700 – 800 meter lang.
- **Traséalternativ 2** har uttak i sørenden av Tangentjernet og går i hovedsak langs eksisterende vei via Rundtjern og Futentass ned til tenkt plassering av stasjonsbygget. I dette alternativet blir rørtraseen 1200 – 1300 meter lang.

Traséalternativ 2 har bakgrunn i Kongsberg kommune Vann og avløps planer for nytt reservevannanlegg, hvor det planlegges en ledning fra Tangentjernet via Rundtjern og Futentass for reservevannanlegg og vanningsmuligheter for park og idrett i idrettsparken. Sweco mener det å se reservevannanlegget og mikrokraftverket i sammenheng framstår som det mest realistiske alternativet for å kunne realisere mikrovannkraftverket innenfor fornuftige økonomiske rammer. Dette kan enten gjøres ved at det legges opp til sambruk av rør og vann, eller ved at vannrør til mikrokraftverket legges parallelt med vannledningen i samme grøft. Sweco anbefaler å se på sambruk av rør og vann, da dette vil gi best utnyttelse.

Figur 7 - Foreslått rørtrase til mikrovannkraftverket, to alternativer.

Figur 8 og 9 viser mer detaljerte rørtraseer og fall. For begge alternativer ser man jevnt fall fra uttak i Tangentjern til planlagt stasjonsbygg.

Figur 8 - Rørtrasé alternativ 1, med uttak på østsiden av Tangentjern.

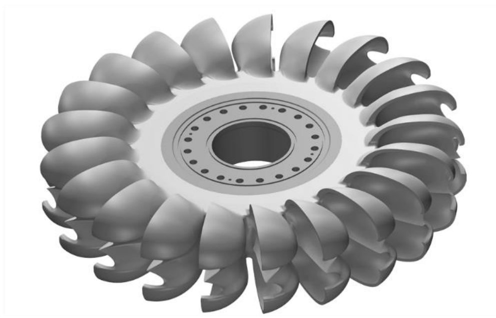


Figur 9 - Rørtrasé alternativ 2, uttak i sørenden av Tangentjern med trasé via Rundtjern og Futentass.

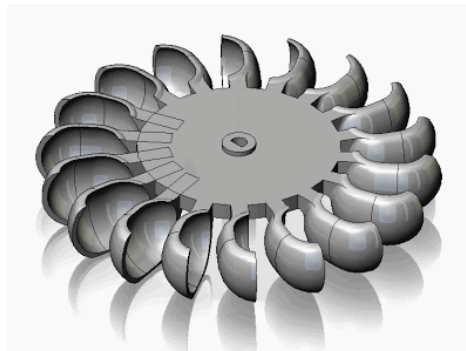
Det anbefales lagt PE-rør med diameter 150 mm. På grunn av begrenset vannmengde bør rørene legges frostfritt. Hvilken dybde dette innebærer vil måtte fastsettes på bakgrunn av lokale forhold, men på generelt grunnlag anbefales en grøftedybde på minimum 1,20 meter. For traséalternativ 1 ventes det å kunne oppstå utfordringer med å nå tilstrekkelig dybde uten sprenging. Ut ifra potensialet for samarbeid eller sambruk med et nytt reservevannanlegg, samt nevnte praktiske utfordringer ved traséalternativ 1 er det en klar anbefaling i det videre arbeidet å fokusere på traséalternativ 2. Denne traseen vil derfor være fokus og utgangspunkt for eksempler og beregninger i resten av rapporten.

2.3 Produksjon

Et mikrovannkraftverk ved Skavanger skole vil karakteriseres av stor fallhøyde og liten vannmengde. Det foreslås derfor å installere en peltonturbin, alternativt en turgoturbin. Dette er begge impulsturbiner beregnet for anvendelser med høyt trykk og relativt liten vannmengde. Illustrasjon av turbin-typene er vist i Figur 10 og 11.



Figur 10 – Illustrasjon av Pelton-turbin



Figur 11 – Illustrasjon av Turgo-turbin

I simulering av produksjon har Sweco sett på tre scenarioer:

- **Scenario 1** er begrenset til nedbørsfeltet til Tangentjernet og produksjonen satt til maksimal realistisk utnyttelse av dette. Scenariet er basert på produksjon tilsvarende utnyttbart tilsig, og vil slik det er presentert her ikke innebære noen større bruk av reguleringsevnen til Tangentjernet.
- **Scenario 2** inkluderer overføring fra Kunstbekken til Tangentjernet. Dette gir et vesentlig større nedbørsfelt og høyere tilsig. I scenariet er årsproduksjonen satt til 50 000 kWh/år, tilsvarende 300 – 350 m^2 solcelleareal. Produksjonen i scenariet ligger betydelig under mulig utnyttbart tilsig, og vil som det er presentert her derfor ikke innebære bruk av reguleringsevnen til Tangentjernet.
- **Scenario 3** er basert på samme forutsetninger som Scenario 2, men utnyttelse av nedbørsfelt og tilsig er vesentlig høyere her. Samlet årsproduksjon i dette scenariet vil være høyere enn behovet ved Skavanger skole, men dette vil kunne brukes til å gi fleksibilitet og redusere ubalanser mellom solenergiproduksjon og energibehov sommer og vinter. Heller ikke dette scenariet innebærer aktiv bruk av reguleringsevnen til Tangentjernet.

Beregninger for alle tre scenarier er basert på rørtraséalternativ 2 da dette anses som mest realistisk gjennomførbart mht. økonomi. Den kortere rørtraseen i traséalternativ 1 vil gi et lavere falltap og dermed mulighet til å hente ut mer effekt fra samme vannmengde. Ved den foreslåtte rørdiameteren – 150 mm – vil imidlertid forskjellene i produksjon være små, i størrelsesorden 2 %. Nøkkeltall for mikrovannkraftverket i de tre scenariene er gjengitt i Tabell 4. Merk at peltonturbinen som brukes i alle tre scenariene er den samme, og at den i Scenario 1 og 2 kjøres på redusert kapasitet.

Tabell 4 - Nøkkeltall for mikrovannkraftverket.

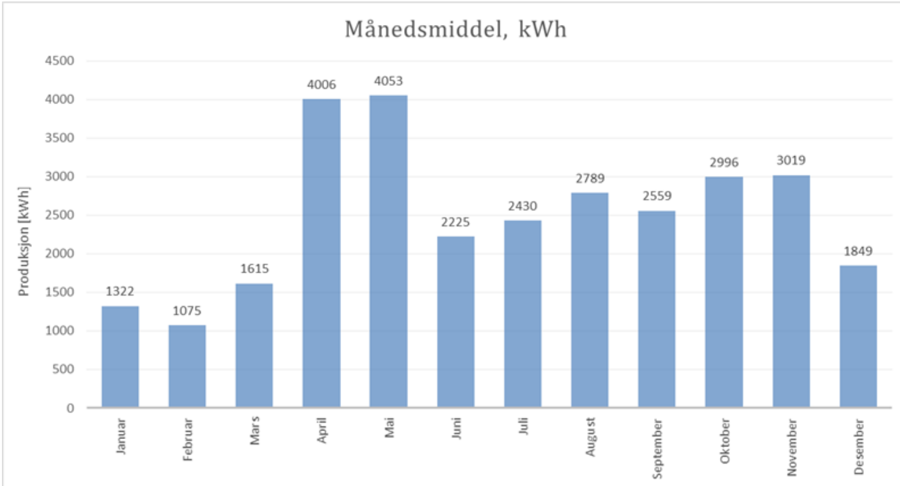
		Scenario 1 Kun Tangentjernet	Scenario 2 Inkludert Kunstbekken	Scenario 3 Inkludert Kunstbekken
Maks slukeevne		90 % av Q_{mid}	13 % av Q_{mid}	80 % av Q_{mid}
Inntak kote	moh	331	331	331
Utløp kote	moh	179	179	179
Brutto fallhøyde	moh	151	151	151
Turbintype	-	Turgo/Pelton	Turgo/Pelton	Pelton
Maks slukeevne	m^3/s	0.0069	0.0067	0.0413
Min slukeevne	m^3/s	0.0004	0.0003	0.0021
Installert effekt	kW	6.5	6.4	28
Rørgate, lengde	meter	1300	1300	1300
Diameter	mm	150	150	150
Rørtype		PE-rør	PE-rør	PE-rør
Absolutt ruhet i rør	mm	0.05	0.05	0.05
Minstevannføring:				
Sommer (1/5-30/9)	m^3/s	0.0	0.0	0.0
Vinter (1/10-30/4)	m^3/s	0.0	0.0	0.0

Tabell 5 viser forventet produksjon for de tre scenarioene splittet på sommer og vinter.

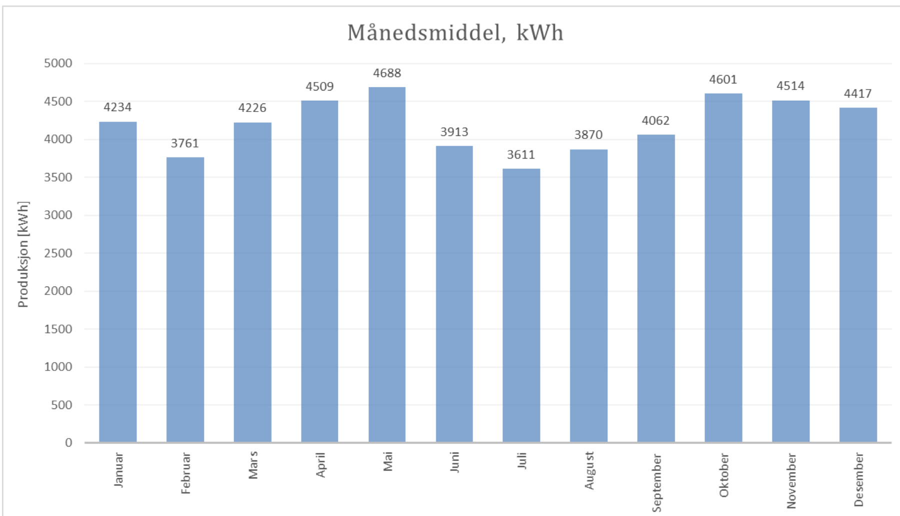
Tabell 5 – Estimert produksjonsimulering for de tre scenarioer.

Senario	Maks slukeevne		Produksjon		
			Sommer	Vinter	Året
	m^3/s	% av Q_{mid}	kWh	kWh	kWh
1	0.0069	90	14100	15900	30000
2	0.0067	13	21000	32000	53000
3	0.0413	80	70700	86400	157100

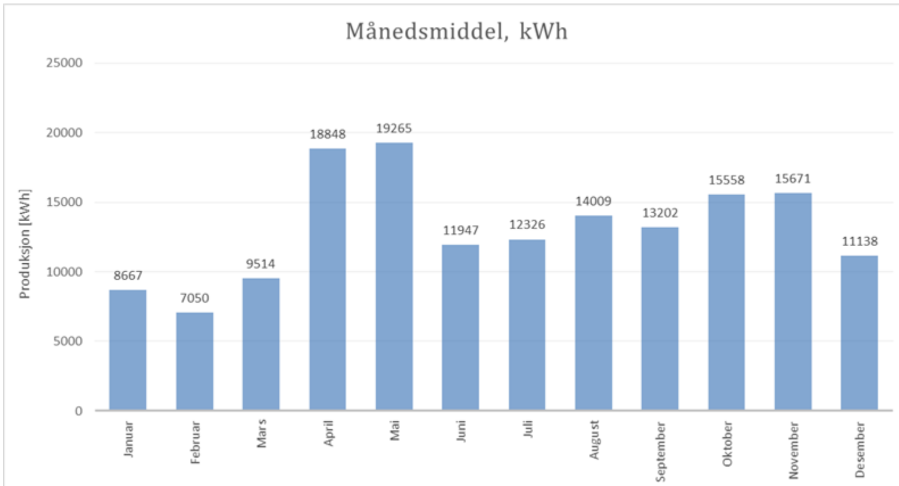
Figur 12 - 14 viser simulert månedlig produksjon for Scenario 1 – 3 basert på nøkkeltallene i Tabell 4. Figurene viser produksjon med en peltonturbin, men fordelingen vil være tilsvarende over månedene også med en turgoturbin.



Figur 12 – Middelproduksjon per måned for Scenario 1, med maks slukeevne på 90 % av Q_{mid}. Produksjon tilpasset maksimal realistisk utnyttelse av tilsiget til Tangentjernet.

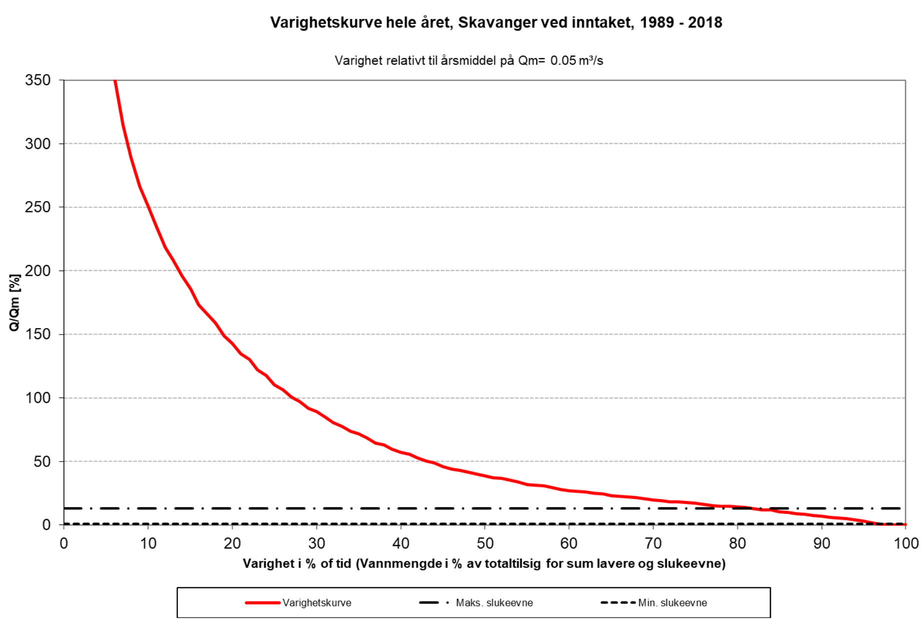


Figur 13 - Middelproduksjon per måned for Scenario 2, med maks slukeevne på 13 % av Q_{mid} og en årsproduksjon på cirka 50 MWh. Inkludert nedslagsfelt til Kunstbekken.



Figur 14 – Potensiell middelproduksjon per måned for Scenario 3, med maks slukeevne på 80 % av Q_{mid}. Inkludert nedslagsfelt til Kunstbekken.

Figur 15 viser varighetskurven for det planlagte mikrovannkraftverket, scenario 2. Her er maks slukeevne vist ved 13 % av Q_{mid}. Varighetskurven sorterer tilsiget til Tangentjern etter størrelse. X-aksen viser prosentdel av dager i året og y-aksen viser prosent av middeltilsiget. Av denne kurven kan en for eksempel finne at for 28 % av året er vannføring lik eller høyere enn middelvannføringen.



Figur 15 - Varighetskurve for scenario 2.

2.4 Kostnadsoverslag

Tabell 5 viser kostnadsoverslaget for mikrovannkraftverket. Kostnadene er basert på innhentet budsjettpriser for rør og elmek-utstyr. Det er hentet priser fra to leverandører som har referanser på anlegg i samme størrelsesorden. Det bemerkes at antall leverandører av utstyr i størrelsene det her er snakk om er svært begrenset.

Tilbudene på elmek-utstyr omfatter komplette kraftverk-pakker. Disse leveres i utgangspunktet som «byggesett», men leverandørene kan også tilby montering. Det er ikke innhentet pristilbud på montering. Kraftverk-pakkene inneholder:

- Turbinkasse
- Asynkrongenerator
- Løpehjul
- Ventil med aktuator
- Kontrollskap med generator, nettvern og hovedkontaktor mot nett

I kostnadsberegningen for rør er det tatt utgangspunkt i traséalternativ 2 (se Figur 6) med en 1300 meter lang rørgate. For denne traseen vil det fortrinnsvis være mulig å få til et samarbeid med Kongsberg kommune Vann og avløp om samarbeid om utbygging eller sambruk av rør. Også uten et slikt samarbeid vil trolig traséalternativ 2 være å foretrekke da dette i all hovedsak vil følge vei. Til tross for at rørkostnaden blir noe høyere forventes dette å gi betydelig lavere kostnader til graving og også mindre behov for terrenginngrep.

Tabell 6 – Kostnadsoverslag mikrovannkraftverk

		Turgo turbin	**Pelton turbin**
Rør driftsvannvei	1300 m à 180 kr/m	Kr 234 000	Kr 243 000
Kraftstasjon, maskin og elektro	Pakkepris (se over)	Kr 150 000	Kr 175 000
Kraftstasjon bygg	Min. 8 m^2	Kr 100 000	Kr 100 000
Kabel kraftverk - skole	250 m à 250 kr/m	Kr 62 500	Kr 62 500
Legging av kabel i bakke	20 t à 1500 kr/t	Kr 30 000	Kr 30 000
Uforutsett	15 %	Kr 86 000	Kr 90 000
Sum utbyggingskostnad		**Kr 662 500**	**Kr 691 500**
Legging av rør	1300 m à 500 – 1000 kr/m	Kr 650 000 – 1 300 000	

Kostnader til legging av rør, kabel og legging av kabel er basert på erfaringstall og ikke innhentede tilbud. Stasjonsbygget er oppført med et nødvendig minimumsareal estimert til 8 m^2. Dette kan evt. gjøres større for å tilrettelegge for visning. I kostnadsoverslaget er det ikke tatt høyde for etablering av uttak fra Tangentjernet. Dette bør søkes løst gjennom bruk av eksisterende uttak til vannledning eller samarbeid/sambruk med det planlagte reservevannanlegget.

3 Forhold til regelverk, planer og andre interessenter

I dette kapittelet omtales hvordan mikrovannkraftverket forholder seg til bl.a. miljø- og verneverdier, areal- og reguleringsplaner, konsesjonsregelverk og det lokale nettselskapet. Det bemerkes at det på det nåværende tidspunkt ikke har vært mulig å få endelige svar eller trekke absolutte konklusjoner, og at dette derfor kan være spørsmål som må tas opp igjen når det foreligger konkrete planer for bygging.

3.1 Miljø- og verneverdier

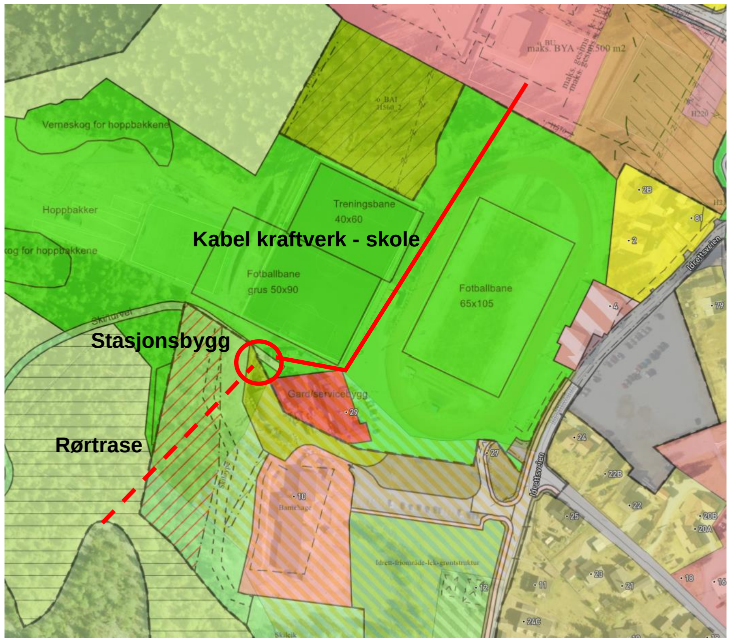
Ved traséalternativ 2 vil tiltaket vil i all hovedsak gjennomføres i direkte tilknytning til eksisterende infrastruktur. Grøfting til rør vil kunne gjøres med minigraver, og grøfter dekkes med stedegne masser. Det ventes derfor ikke å ha nevneverdig innvirkning på miljø- eller verneverdier. Et mulig unntak er den nederste delen av rørtraseen som tenkes trukket fra Stollveien til Kongsberg idrettspark. Her ble det i forbindelse med reguleringsarbeidet for Idrettsparken barnehage (plan 441) registrert et steingjerde på planområdet som ble ansett som et kulturminne knyttet til løkkelandskap. I bestemmelsene til reguleringsplanen (441R) er det fastsatt at dette skal bevares, og ikke endres eller flyttes (§ 5.9 b). Dette må hensyntas ved detaljert fastsetting av rørtrasé.

3.2 Areal og regulering

Størstedelen av rørtraseen vil følge Stollveien. Denne ligger i område regulert til LNRF i gjeldende kommuneplan (KPLAN13). Nedre del av rørtraseen vil krysse over område avsatt til friluftsområde i reguleringsplan for Idrettsparken-Blekajordet (plan 204) og friområde i reguleringsplan for Idrettsparken barnehage (plan 441). Deler av nedre del av traseen vil også gå gjennom et område definert som faresone – ras- og skredfare (snøskred). I og med at det her er snakk om et tiltak under bakkeplan som ikke vil «legge opp til bruk av området» anser vi ikke tiltaket som i strid med bestemmelsene for faresonen (441R, § 9.1 a).

Stasjonsbygget foreslås plassert på sørsiden av idrettsparken i tilknytning til eiendom 7716/1 eller 7716/6. Disse er regulert til hhv. idrettsanlegg og garderobe-servicebygg. Stasjonsbygget vil uten problemer kunne tilpasses bestemmelsene som er gitt i reguleringsbestemmelsene (reguleringsbestemmelser for Byplan 204).

Kabel mellom kraftverk og skole vil krysse område avsatt til anlegg for idrett og sport i reguleringsplan for Idrettsparken-Blekajordet (plan 204) og område avsatt til undervisning i reguleringsplan for Skavanger skole (515R). I sistnevnte er det krav til at nye høyspentlinjer og fordelingsnett for strømforsyning skal legges som jordkabler, men dette kan med fordel legges til grunn for hele strekket.



Figur 16 – Plankart med forslag til rørtrase, stasjonsbygg og kabel kraftverk – skole markert

3.3 Konsesjon

Mikrovannkraftverket er med god margin under grensen NVE anbefaler for konsesjonssøknad (1 MW) og innebærer ingen nye dammer, ny regulering eller andre tiltak som gjør at konsesjonsplikt likevel kan være aktuelt. Mikrovannkraftverket vil etter Swecos vurdering ikke være konsesjonspliktig, og søknad om konsesjonsfritak sendes NVE. Dersom NVE fatter vedtak om konsesjonsfritak så behandles prosjektet videre av Kongsberg kommune etter plan- og bygningsloven.

3.4 Nett

Mikrovannkraftverket vil ikke skille seg fra f.eks. solcelleanlegg med hensyn til installert effekt og årsproduksjon. Det forutsettes derfor at produksjonen fra mikrovannkraftverket kan mates direkte til Skavanger skole uten å måtte gå via nettet. Tekniske krav til tilkoblingen mm. må avklares med nettselskapet.

3.5 Andre interessenter

I e-post fra Tor Arne Folseraas, VTA for Kongsberg kommune, datert 17.01.20 opplyses det at Kongsberg skisenter normalt bruker 1 meter av reguleringen i Tangentjernet fra november til februar. Så vidt Folseraas kjenner til finnes det ikke noen skriftlig avtale om dette, men det anses som «politisk viktig» i kommunen- Produksjonsestimatene presentert i rapporten er basert på forutsetninger som gjør at mikrovannkraftverket i utgangspunktet ikke vil komme i konflikt med dette. Ved aktiv bruk til regulering av sommer-vinter ubalanser i solenergiproduksjon kan det imidlertid ikke utelukkes at det i enkelte år kan oppstå situasjoner hvor disse interessene vil være i konflikt. Det bør derfor vurderes om det er behov for å formalisere en avtale med Kongsberg skisenter.

Folseraas skriver videre at Kongsberg kommune har behov for et visst nivå i magasinet som reserve/nødberedskap. Også dette vil være uproblematisk så lenge mikrokraftverket baseres på tilsig alene, men ved ønske om aktiv bruk av mikrovannkraftverket til regulering av ubalanser i solenergiproduksjon bør det vurderes om det er behov for å inngå en avtale med Kongsberg kommune om prioriteringer for bruk av vann fra Tangentjern. Kongsberg skisenter bør også inngå som part i en slik avtale.

4 Konklusjoner

Rapporten omhandler muligheter for etablering av et mikrovannkraftverk tilknyttet Skavanger skole med vann fra Tangentjernet. Målet er å få til en produksjon som kan erstatte 300 m^2 solcelleareal, dette tilsvarer en produksjon på ca. 50 000 kWh/år. Skavanger skole er planlagt bygget etter FutureBuilts plusshus-definisjon, som her gir behov for en egenproduksjon av energi på 134 266 kWh/år.

I rapporten vurderes to alternative rørtraseer og tre ulike produksjonsscenarier. En rørtrase fra Tangentjernet via Rundtjern og Futentass som i hovedsak følger Stollveien blir funnet å være det beste alternativt. Denne gir muligheter for samarbeid/sambruk med en planlagt utbygging av et nytt reservevannanlegg fra Tangentjern i regi Kongsberg kommune vann og avløp, og forventes uavhengig av dette å gi lavere kostnader og mindre behov for naturinngrep. Rørtraseen blir ca. 1300 meter lang med brutto fallhøyde 151 meter.

Produksjonsscenariene baseres på hhv. full utnyttelse av tilgjengelig tilsig til Tangentjern, en årsproduksjon på 50 000 kWh fra Tangentjernet med overføring fra Kunstbekken, og full utnyttelse av tilgjengelig tilsig fra Tangentjernet med overføring fra Kunstbekken. Overføringen fra Kunstbekken gir en betydelig økning i nedbørsfeltet til Tangentjernet, og gir slik mulighet for høyere produksjon og mer fleksibilitet. Avhengig av driftsopplegg estimeres mikrovannkraftverket å kunne redusere underproduksjonen om vinteren med mellom 13 000 kWh og 35 000 kWh, og tilsvarende redusere overproduksjonen om sommeren med mellom 11 000 kWh og 31 500 kWh.

Kostnadene forbundet med bygging av mikrovannkraftverket vil være dominert av kostnader til rørgate. Økonomien i prosjektet vil derfor være sterkt avhengig av mulighetene for samarbeid eller sambruk med nevnte utbygging av nytt reservevannanlegg. Eksklusive kostnader til grøfting og legging av rør estimeres samlede kostnader til ca. kr 700 000. Kostnader til grøfting og legging av rør estimeres til et sted mellom kr 650 000 og kr 1 300 000.

Prosjektet forventes ikke å gi vesentlige utfordringer mht. regelverk, planer eller andre interesser, men det bør vurderes å inngå/formalisere avtaler om bruk av vann med Kongsberg skisenter og

Kongsberg kommune. Dette vil være spesielt viktig ved aktiv bruk av mikrovannkraftverket til å redusere ubalanser solenergiproduksjon i produksjon mellom vinter og sommer.

SWECO

5 Vedlegg – E-post fra Tor Arne Folserås, VTA Kongsberg

Fra: Tor Arne Folserås <torarne@l-fossum.no>
Sendt: fredag 17. januar 2020 11:54
Til: Hallvard Benum <Hallvard.Benum@kongsberg.kommune.no>
Kopi: Carolin Forsberg Gulbrandsen <carolin.forsberg.gulbrandsen@kongsberg.kommune.no>; Eirik Brunvoll <eirik.brunvoll@kongsberg.kommune.no>
Emne: SV: Project in Kongsberg Norway

Hei
Viser til e-post kopi i fra Carolin

Vedlegger kopi av flomberegningene, ut fra de kan det beregnes det som trengs mhp prosjektering av micro kraftverk. Reguleringshøydyden i Tangentjern er 6m mellom HRV og LRV, som vi har disponibelt, anleggene er konsesjonsfrie og derfor finnes ikke data hos NVE. Det finnes ingen restriksjoner, med unntak av en at Tangentjern er etter henvendelse fra Kongsberg Skisenter, bruker magasinkapasitet til etterfylling i avløpsbekken (for økt vannføring) høst og vinter, for snø produksjon til Kongsberg skisenter. Noe som etter hvert er blitt en innarbeidet «vane». og som politisk er viktig i kommunen. Meg bekjent så finnes ikke en skriftlig avtale på dette! Mulig du Carolin kan mer om dette!

Normalt så har Kongsberg skisenter brukt 1m av reguleringen i fra november til februar!

Det nye reservevannanlegget har fått inntak i Tangentjern og legges i rør gjennom Rundetjern før det føres videre ned mot Futentas. Kjenner ikke til hvor det der går videre men regner med at det da kan kobles inn på ordinært vann nettet. Dvs at det ikke vil være noe inntak i fra Rundetjern lengre. I og med at inntaket nå blir i Tangentjern så blir dermed trykket «høyt» for drikkevannsnettet opp mot 17bar og det vil derfor måtte settes inn tiltak «reduksjonsventiler» for at vannrør ventiler osv. ikke skal «sprenges» Dette er ikke gunstig for kraftverk hvor man ønsker trykket så høyt som mulig! Dette kan løses med omløpsventiler forutsatt tilstrekkelig styrke i rør (PN20 for nedre del).

Ingen ekstra hensyn ut over normal byggesøknad, og de planene som alt eksistere mhp rørtrase. Heller ikke for et eventuelt kraftstasjonsbygg. Rørtraseen for et kraftverk bør alltid være så kort som mulig. Det er mye større friksjonstap i rør enn i strømkabler dessuten er strømkabler billigere enn rørgater ved større dimensjoner. Bør vel i dette tilfelle opp i en rørdiameter på ø125mm til ø150mm for ikke å få for stort falltap (kjenner ikke diameteren på planlagt reserve vannrør). Falltap i vannvei kan kompenseres med større rørdiameter om kraftversbygget legges tett ved forbrukssted. I motsatt fall så kommer el og nettkonsesjons problematikk inn, i verste fall må strømmen går om forsyningsnettet. Mener det finnes unntak i regelverk for micro anlegg. Veit det finnes «gårsbruk» som har toveis målere hvor anleggseier, eier kabel fra produksjonssted til forbrukssted og hvor da tilknytningspunktet til øvrig strømnett er i vegg forbrukssted. For større mini og småkraftverk så er ikke dette tillatt fordi blant annet, så snyter man da staten for el avgifter. Dvs at strømmen må selges direkte på nett og leveres forbruker via nettkonsesjonær i dette tilfelle lokalt e-verk «Netteier».

Forutsatt at overføringen til kunstbekken opprettholdes så er nedslagsfeltet til Tangentjern 2,87 km2, spesifikk avrenning 19 l/km2 dvs middel avrenning på ca. 54 l/s sannsynlig ville det kunne ha et uttak på opp mot 35%-50% (god reguleringsgrad/dempning i feltet) av Qm dvs. 20 l/s uten større konflikter. Maks effekt mikrokraftverk ville da kunne bli rundt 15-20kW redusert for tap. Da ville man måtte gjøre en prioriterings avtale med kommune og Kongsberg Skisenter i forhold til bruk av magasin. Hoved utfordringen blir vel Kommunens reserve/nød beredskap hvor mye må det til en hver tid ha i magasinet for å ha tilstrekkelig beredskap. Tilløp/avløpsvann ved fullt magasin vil til enhver tid være uproblematisk å bruke.

Mvh

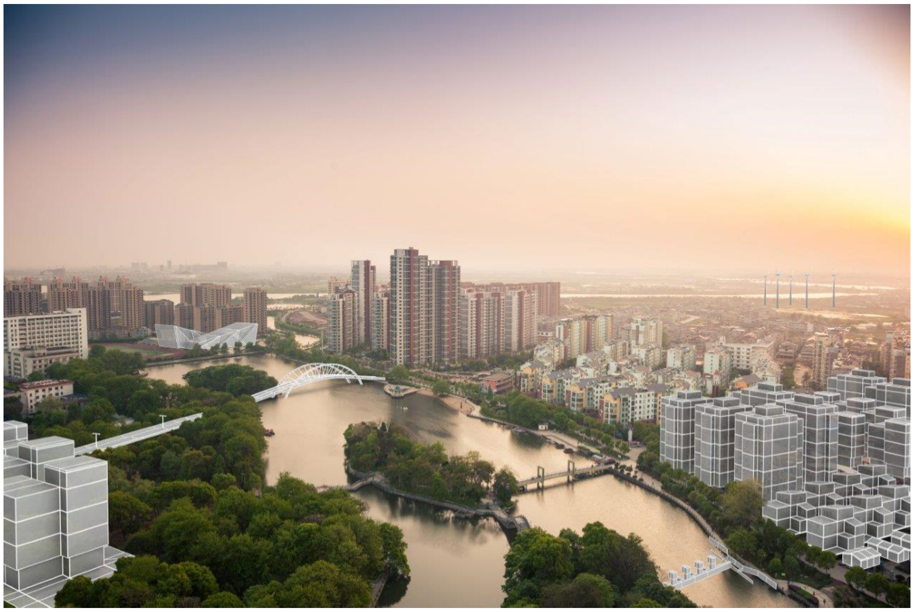
Tor Arne Folseraas
Sivilingeniør Vannkraftanlegg
VTA for Kongsberg Kommune

C Extracts from Sweco's Report on Thermochemical Storage

SWECO

RAPPORT

Utredning av sesonglagring av strøm ved bruk av Saltx (termokjemisk lagring) for Skavanger Skole



Kunde:	Kongsberg kommune
Prosjekt:	Sesonglagring av strøm ved bruk av SaltX
Prosjektnummer:	10216192
Dokumentnummer:	RIEN 2020 Rev.: 0

SWECO

Sammendrag:

Kongsberg kommune har fått klimasatsmidler for å utrede bruk av SaltX for sesonglagring av strøm. På oppdrag fra kommunen har Sweco Norge utredet konseptet for Skavanger Skole. I denne rapporten har Sweco utredet tekniske, økonomiske og praktiske forhold rundt bruk av SaltX for sesonglagring for Skavanger Skole. Arbeidet har blitt utført i tett dialog med aktuelle utviklingsselskap som står bak teknologimulighetene og mye av underlaget baserer seg på informasjon hentet fra SaltX. Vår vurdering viser at det er mulig å lagre strøm ved termokjemisk prosess over lang tid ved bruk av SaltX teknologi. Imidlertid vil «round-trip» elektrisk virkningsgrad ligge på nærmere 10%. Systemet gir ca. 72% termisk virkningsgrad, altså ca. 82% totalvirkningsgrad. Selve den termokjemiske lagringen av energien gir virkningsgrad på nærmere 94%. Den lave el-til-el virkningsgrad skyldes hovedsakelig tilgjengelig CHP-teknologi i markedet, både mtp. forventet virkningsgrad og kapasitet. Videre må systemet ha et godt samspill med bygget, slik at overskuddsvarme kan benyttes til oppvarmingsformål for å oppnå høy varmegjenvinning og høy totalvirkningsgrad for systemet.

Utredningen estimerer et investeringsbehov på ca. 18,7 MNOK inkl. mva for lagring av 10 000 kWh energi (altså 16 500 kWh inngående strøm til lagring av 10 000 kWh til produksjon av 1 500 kWh strøm og 11 800 kWh varme). Anlegget vil ha et plassbehov på ca. 200 m² med 8 m takhøyde. Både kostnader og plassbehov anses noe høyere på grunn av prosjektets innovasjonsart med lite erfaring fra tilsvarende anlegg utført før i Norge. Det anbefales at prosjektet derfor ikke gjennomføres som en vanlig entreprise. Prosjektet bør gjennomføres som et innovasjonsprosjekt som gir rom for samspill mellom alle involverte for å redusere teknisk risiko. Prosjektet anbefales å søke ENOVA og/eller andre mulige støtteordninger.

I denne utredningen har fokuset vært på overordnet konsept, men det anbefales å undersøke andre CHP-alternativer som kan gi bedre elektrisk virkningsgrad og egnet termisk kapasitet. Utredning viser at prosjektet er gjennomførbart med høy demonstrasjons- og spredningseffekt og anbefales testet som et pilotprosjekt for dokumentasjon av teknologianvendelse.

Rapporteringsstatus:

☒ Endelig
☐ Oversendelse for kommentar
☐ Utkast

Utarbeidet av: Usman Dar	**Sign.:** Digitally signed by usman dar Date: 2020.03.13 13:32:21 +01'00'
Kontrollert av: Elin Skjerven Talhaug	**Sign.:** Digitally signed by Elin Skjerven Talhaug Reason: KS Date: 2020.03.13 16:43:44 +01'00'
Prosjektleder: Usman Dar	**Prosjekteier:** Anette Amble Svortevik Sunde

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Revisjonshistorikk:

Rev.	Dato	Beskrivelse	Utarbeidet av	Kontrollert av
0	13.03.2020	Utredning av sesonglagring av strøm ved bruk av Saltx (termokjemisklagring) for Skavanger Skole	NOUSMA	NOELSK

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Innholdsfortegnelse

1 Prosjekts premisser

1.1 Innledning

Det skal bygges en ny barneskole hvor eksisterende skole skal rives. Nytt bygg er på to etasjer og har en grunnflate på 1750 m² med totalt bruksareal på ca. 3500 m². Skolen dimensjoneres for 2 klasser pr. trinn med 275 elever og ca. 30 ansatte.

Tabell 1: Overordnet tall for skolebygg (benyttes som underlag for utredning)

Dokumentasjon av sentrale inndata (1)		
Beskrivelse	Verdi	Dokumentasjon
Areal yttervegger [m²]:	1706	
Areal tak [m²]:	1656	
Areal gulv [m²]:	1656	
Areal vinduer og ytterdører [m²]:	407	
Oppvarmet bruksareal (BRA) [m²]:	3301	
Oppvarmet luftvolum [m³]:	12783	
U-verdi yttervegger [W/m²K]	0,17	
U-verdi tak [W/m²K]	0,09	
U-verdi gulv [W/m²K]	0,08	
U-verdi vinduer og ytterdører [W/m²K]	0,63	
Areal vinduer og dører delt på bruksareal [%]	12,3	
Normalisert kuldebroverdi [W/m²K]:	0,02	
Normalisert varmekapasitet [Wh/m²K]	56	
Lekkasjetall (n50) [1/h]:	0,30	
Temperaturvirkningsgr. varmegjenvinner [%]:	85	

Skolen skal bygges som plusshus skole i tråd med Kongsberg kommune sin klimastrategi. Det betyr at bygget blir passivhus, med svært energieffektiv bygningskropp og høygrad av energieffektive tekniske installasjoner. I tillegg vil skolen ha større del av takarealet dekket av solcelleanlegg for å innfri plusshus definisjonen. Skolen vil benytte varmepumpe for å dekke hovedandel av varmebehovet, mens el-kjel vil dekke spisslast og fungere som back-up.

Solcelleanlegg vil produsere mest solstrøm om sommeren, også i perioden der skolen har sommerferie. Både energieffektive løsninger og sommerferie bidrar til at mesteparten av solstrømmen må eksporteres fra bygget og føres inn på strømnettet. Selv om dagens definisjoner for plusshus og nullutslippsbygg veier energibalanse på årlig nivå, betraktes den sesongmessige ubalansen mellom behov og produksjon som en utfordring på langsikt. Derfor ønskes det å teste et konsept for sesonglagring av strøm som bruker termokjemiske prosesser for å lagre energien. Konseptet muliggjør lagring av overskuddsstrøm om sommeren som senere kan benyttes om vinteren. Denne rapporten utreder bruk av dette konseptet for Skavanger skole.

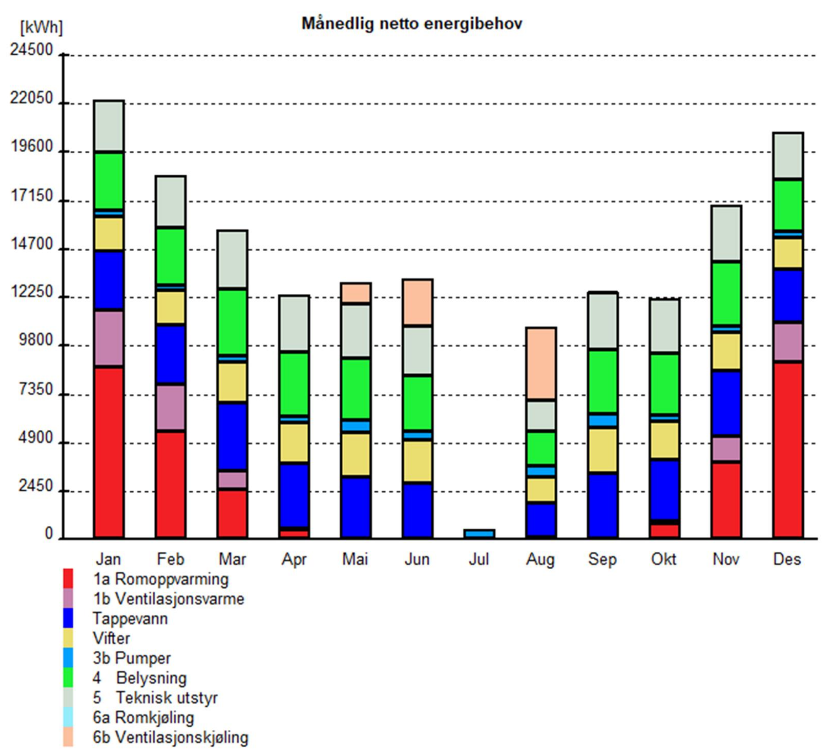
1.2 Energi og effektbehov

Utredningen har benyttet energisimulering utført av Rambøll som underlag for effekt- og energibehov for skolen. Tabell 2 og Tabell 3 viser effekt- og energibehov til skolen. Skolen kommer til å ha et dimensjonerende oppvarmingsbehov på ca 140 kW, beregnet av RIV (litt høyere enn 120 kW vist i tabellen nedenfor). I tillegg vil det komme et behov på ca. 15 kW til oppvarming av tappevann. Det skal også leveres ca 37 kW (70 % effektdekning) til gymbygget. Varmeanlegget vil ha en dimensjonerende turtemperatur på 40°C, med mulighet for drift på 32°C mesteparten av tiden. Det benyttes propanvarmepumpe som produserer varme opp til 40°C og vil dekke grunnlast varme. Figur 1 viser månedlig oppdeling av beregnet netto energibehov for skole.

Tabell 2: Brutto effektbehov til oppvarming for Skavanger skole (Oslo klima)

Dimensjonerende verdier		
Beskrivelse	Verdi	Tidspunkt
Maks. samtidig effekt varmebatterier:	56,8 kW / 17,2 W/m²	07:00
Totalt installert effekt varmebatterier	99,0 kW / 30,0 W/m²	07:00
Maks. samtidig effekt romoppvarming:	62,8 kW / 19,0 W/m²	07:00
Totalt installert effekt romoppvarming	165,1 kW / 50,0 W/m²	07:00
Min. romlufttemperatur:	19,0 °C	07:00
Min. operativ temperatur:	19,0 °C	07:00
Maksimal CO2 konsentrasjon (Fløy, klasserom)	691 PPM	13:30

Tabell 3: Netto beregnede energibehov for Skavanger skole (lokalklima)



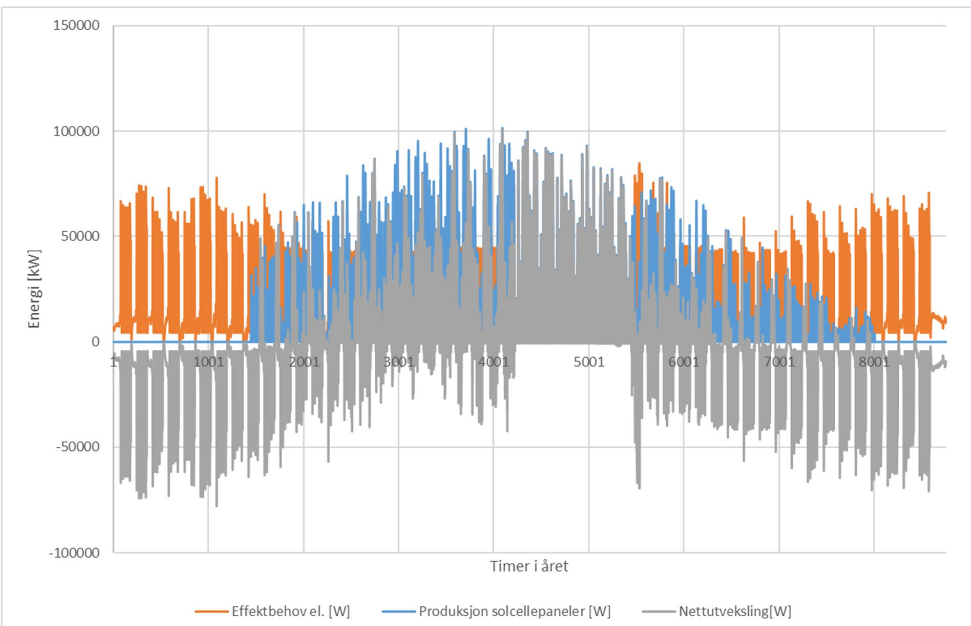
Figur 1: Månedlig netto beregnet energibehov for Skavanger Skole

1.3 Solstrøm produksjon og batterilagring

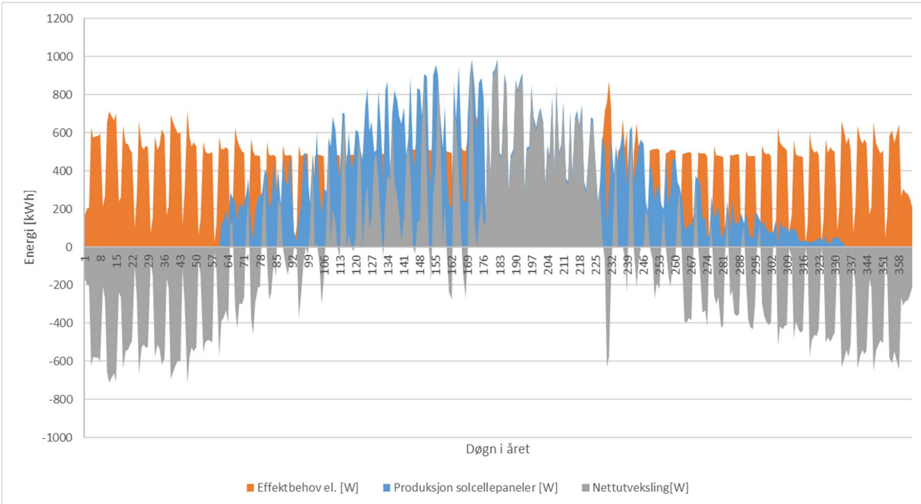
Skolen vil ha et solcelleanlegg i størrelsesorden 950 m², ca. 150 kWp solcelleanlegg med forventet produksjon på 118.000 kWh. Solcelleproduksjon kommer i motfase til energibehovet til bygget. Analyse tydeliggjøre disse ubalanser på time, døgn og månedsnivå i Figur 2, 3 og 4.

Figurer viser at produksjon fra solcelleanlegg varierer i takt med solstråling. Både momentan og daglig produksjon fra solcelleanlegg kan variere mye. En solrik dag kan gi produksjon opp mot 1000 kWh. Noe av denne produksjonen vil kunne brukes direkte i bygget, mens resten må enten eksporteres eller lagres. For å øke egenbruk av solstrøm i bygget har skolen planlagt å installere en 150 kWt batteripakke. Batteripakken vil bidra til å lagre solstrøm mens sol-produksjon er høyere enn forbruket (overskudd – for eksempel på en solrik dag) til senere bruk når sol-produksjon er lavere enn forbruket (underskudd - for eksempel om kvelden). Batterilagring vil bidra til å jevne ut variasjoner over dagen mellom forbruk og produksjon. Imidlertid har en batteripakke på 150 kWt ikke nok kapasitet for langtidslagring av overskuddet. Batteriteknologien har også tekniske utfordringer som hindrer bruk av batteri til langtidslagringsformål.

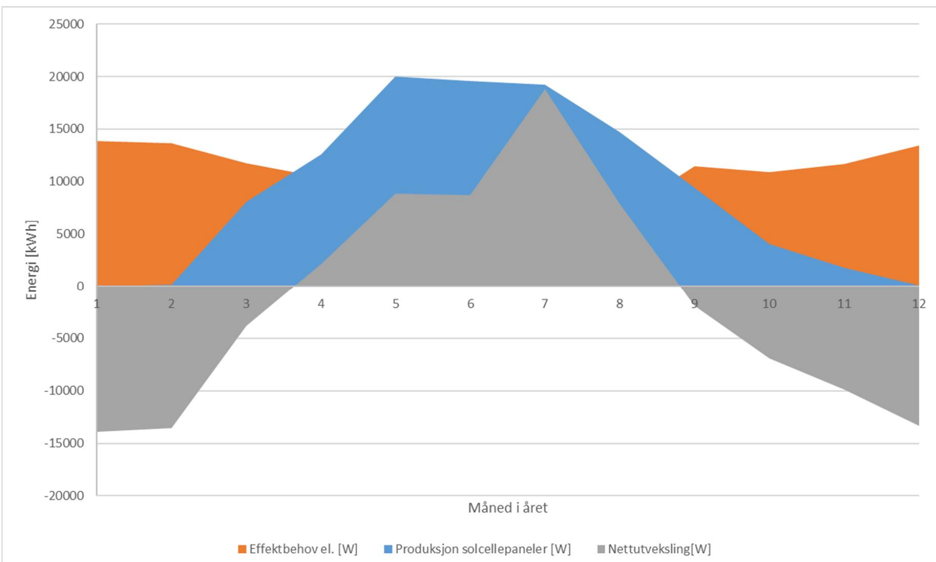
Byggets forbruk, solstrømproduksjon og forventet overskudd er analysert på times-, døgn- og månedsnivå i Figur 2, 3 og 4. Resultat på døgn og månedsnivå viser tydelig overskudd om sommeren. Nettutveksling analyse på timenivå gir ca. 50 000 kWh overskudd solstrøm som kan sesonglagres til fordel for å øke byggets egen forbruk.



Figur 2: Timesprofil for el-forbruket, solstrøm og energibalanse for Skavanger Skole (med batteri)



Figur 3: Estimert daglig profil for el-forbruket, solstrøm og nettutveksling for Skavanger Skole (med batteri)



Figur 4: Månedlig elforbruket, elproduksjon og nettutveksling (med batteri)

2 Sesongslagring av solstrøm

Figur 5 nedenfor viser overordnet konsept for kjemisk lagring av strøm over lengre tid. Konseptet omfatter bruk av lesket kalk til termokjemisk lagring av energi. Prosess kan beskrives i følgende steg:

4.	Hjelpeutstyr og rør		500 000 NOK
5.	Elektro og automatikk		250 000 NOK
6.	Rigg og drift		300 000 NOK
7.	Prosjektering		250 000 NOK
	Sum		**11 750 000 NOK**
8.	Uforutsatt	± 30%	3 500 000 NOK
9	Totalentreprise kostnader eks mva		**≈ 15 000 000 NOK**
10	Mva	+25 %	3 725 000 NOK
11	Totalprosjektskostander ink. Mva		18 725 000 NOK
Kronekurs basert på 01.03.2020.			

2.6 Innovasjon og uforutsatt

Konseptet omfatter anvendelse av teknologi som ikke har vært kommersialisert og kun har vært realisert i begrenset omfang. EnerStore/SaltX har sitt første storskala prosjekt i Tyskland sammen med Vattenfall fjernvarme. Selve CHP-teknologier har vært i bruk i noe større omfang, men har hatt tilnærmet ingen eksempler i Norge. Derfor må det forventes utfordringer av både teknisk og ikke-teknisk art i både planlegging, prosjektering, utførelse og drift. Det er derfor viktig at et slikt prosjekt defineres i en kategori under innovasjon og pilotforsøk, og ikke under en kategori som vanlig energisentral for et bygg. Investering i et slikt anlegg vil gi inngående kunnskap på nasjonalt nivå, som vil kunne benyttes på tvers av sektorer for å møte morgendagens høyst aktuelle utfordringer.

3 Konklusjon

Utredningen viser at sesonglagring av strøm ved bruk av termokjemisk prosess er mulig. Elektrisk «roundtrip» virkningsgrad for systemet vil ligge på på ca.10% mens termisk «roundtrip» virkningsgrad vil ligge på nærmere 72% avhengig av varmeutnyttelse i bygget. Utredningen er utført for termokjemisk lagring av ca. 10 000 kWh (varme) og vil ha et investeringsbehov på ca. 18,7 MNOK inkl mva. Systemet vil kreve et teknisk rom på ca. 200 m² med minimum 8 m høyde. Kostnad for selve teknisk rom er ikke tatt med i kalkyle. Konseptet viser et lagringsalternativ som er høyst aktuelt i en energiinfrastruktur med høy andel av fornybar energi. Det er ikke utført lønnsomhetsanalyse for teknologien. Med dagens strømpriser og estimert investeringsbehov vil prosjektet på ingen måte gi noe lønnsom drift på kort eller lang sikt i tilkobling med enkeltbygg. Anvendelse av teknologi i dette prosjektet anses som et pilotprosjekt med høy demonstrasjons- og spredningseffekt.

The Energy System of Skavanger School

Synstad, Ekren and Onsrud

NTNU
Kunnskap for en bedre verden