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Conceptual modeling of energy storage systems

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Abstract. Conceptual models are explicit representations of complex systems that help people understand and communicate the system and its behavior in its actual context. The stable energy systems that we rely on in our daily life require a balance between energy production and consumption. Energy systems, particularly those that include renewable energy sources, have inherent dynamic behavior due to the intermittence of energy sources such as solar and wind. We use conceptual models to understand this behavior.

The transition towards a carbon neutral energy system requires energy storage to ensure a supply of renewable energy when needed. The sizing strategy for energy storage systems is challenging because both the supply side and the demand side varies with time. In this paper, we investigate how energy storage technologies can provide seasonal storage for an existing energy system with excess electric power production during the summer months. We use conceptual models to review pumped hydro energy storage, hydrogen storage, and brine technology.

The conceptual models simplify the selection process and help in choosing the most suitable energy storage solution from technical and economic criteria. The conceptual models are effective in communicating the constraints and opportunities of the system. However, we find it difficult to balance between comprehension that requires simplification, and accuracy that requires details.

Introduction

Conceptual modeling helps to present and visualize information in complex systems. A conceptual model presents the relationships between a set of elements within a system. The main purpose of a conceptual model is to help people reason, communicate and make decisions regarding a problem (Muller, 2014).

Conceptual models are combinations of visualizations, mathematical formulas, and quantitative calculations. Conceptual modeling can take place at any time during a simulation study, and it is an iterative process where the model is continuously changing (Robinson, 2008).

We develop conceptual models to help experts reason about their system and communicate the system characteristics to decision-makers. Although we develop models for the experts, the models need to meet the goals of the decision-makers. Figure 1 illustrates how the different instances connect and relate to each other.

The experts use their knowledge and expertise to provide options, and the impacts of these options, to the decision-makers. The decision-makers are the interface to society, and they will consider the solutions based on the signals from society and other constraints such as economic, legal, and environmental constraints. The decision-makers can allocate resources to the executors when they have decided on a specific solution (Muller, 2020).

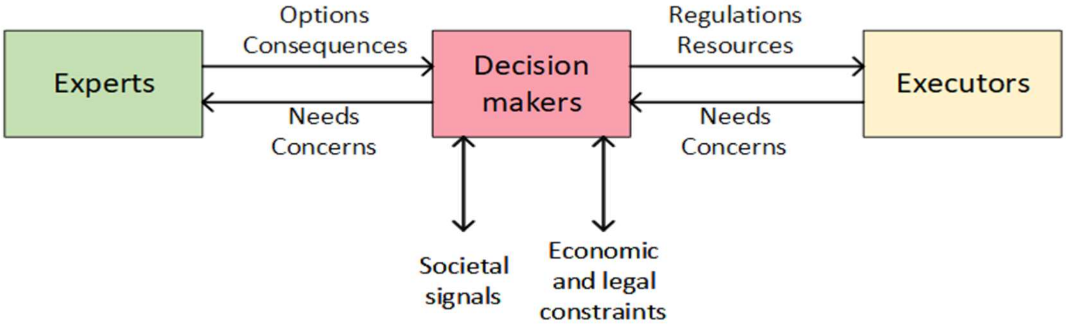


Figure 1: The relationship between experts, decision-makers, and executors (Muller, 2020)

The goal of this study is to understand the use of conceptual modeling when communicating and exploring systems for energy storage. This study builds on the preliminary work of the third author (Muller, 2020). We adapt the methodology to a small-scale energy storage project at Vestsiden middle school in the city of Kongsberg, Norway.

The Vestsiden school building is a powerhouse (Kongsberg kommune, 2019b). A powerhouse is a building that produces more electric power than it consumes during the building lifecycle, including construction and decommissioning/disposal. The building owner has installed more than 1000 solar panel on the building. We use actual data from this system to develop methodologies to size energy storage systems using conceptual modeling.

Renewable Energy System with Storage. The goal of the Paris Agreement from 2016 is "to avoid dangerous climate change by limiting global warming to well below 2°C and pursuing efforts to limit it to 1.5°C" (European Commission, 2019). The world's energy production and use are the largest sources of global greenhouse gas emissions (IEA, 2019). Therefore, changes in the energy sector are crucial to achieving the temperature goal.

The transition from fossil fuels to renewable energy sources is essential to ensure a sustainable world with lower CO_2 emissions. The production of renewable energy from solar and wind varies from day to day. A surplus of energy may occur when we produce more energy than there is a demand for in the market or an energy deficit due to a higher demand than production. This intermittency problem is a challenge when having a grid based on renewable energy sources. Energy storage is a solution to cope with the variations in production and demand, and can potentially level the unbalance.

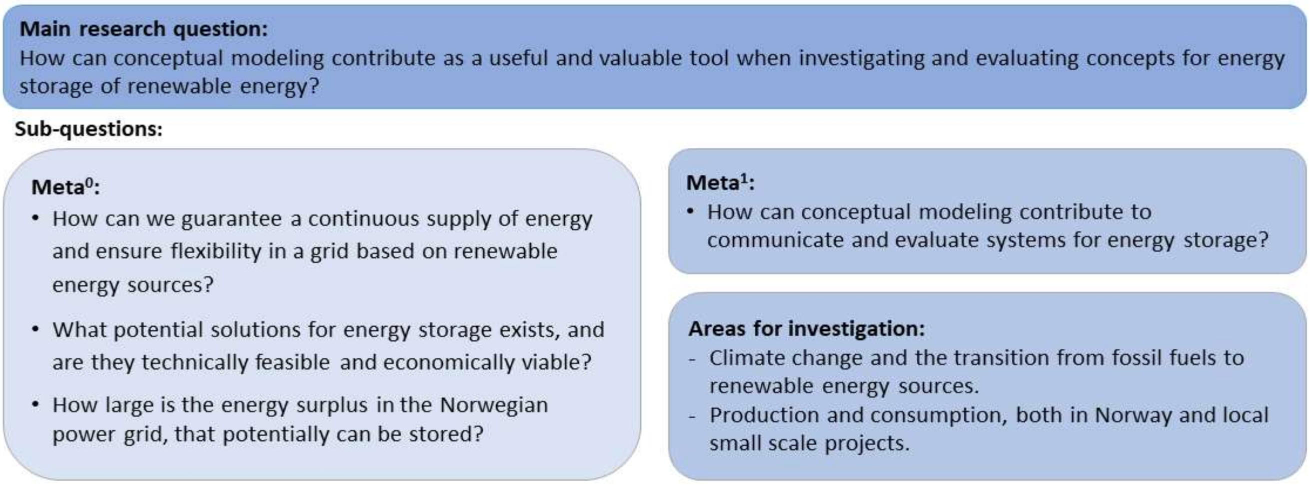
Energy storage technologies are diverse and expanding. Batteries will help resolve intermittency issues in the short-term time scale (hours and days). However, the alternatives for long-term energy storage are not yet economically viable and competitive (IIASA, 2020).

Energy storage potential. Norway is big on renewables, particularly hydropower. The Norwegian hydropower system is partially flexible due to large hydroelectric power system with over 800 lakes and dams and 1600 power stations (NVE, 2019). We can only regulate the hydropower stations that have water reservoirs. There is limited capability to regulate the power produced from power stations in rivers.

Norway has considerable potential for wind power and a significant amount of solar energy during the summer. Increasing the renewable power in the energy system requires additional system flexibility from energy storage for grid balance in the long-term, seasonal perspective. The objectives of energy storage are a) to guarantee the supply of power from renewable energy sources, and b) to ensure flexibility in the grid.

The city of Kongsberg in Norway wishes to adopt new technology and environmentally friendly solutions. By 2030 the goal is to become close to a zero-emission society (Kongsberg kommune, 2018). 13% of the CO_2 emissions in Kongsberg are from energy consumption in buildings (Larsen, Hognes, & Raabe, 2018). The city intends to install renewable energy production and to consider energy storage systems in new public buildings.

Research questions. The basis for this study is the research questions presented in Figure 22. In addition to one main research question, we have categorized the sub-questions as Meta^0 and Meta^1 questions. Meta^0 revolves around the system-of-interest, which is energy storage, and Meta^1, the systems engineering method (Kokkula et al. 2020).



Main research question:
How can conceptual modeling contribute as a useful and valuable tool when investigating and evaluating concepts for energy storage of renewable energy?

Sub-questions:

Meta^0:
- How can we guarantee a continuous supply of energy and ensure flexibility in a grid based on renewable energy sources?
- What potential solutions for energy storage exists, and are they technically feasible and economically viable?
- How large is the energy surplus in the Norwegian power grid, that potentially can be stored?

Meta^1:
- How can conceptual modeling contribute to communicate and evaluate systems for energy storage?

Areas for investigation:
- Climate change and the transition from fossil fuels to renewable energy sources.
- Production and consumption, both in Norway and local small scale projects.

Figure 2: Research questions

Research design

Figure 3 illustrates the research design we use in this study. The process consists of five main steps: Identification, Data gathering, Interpretation, Conceptual modeling and Completion. Figure 3 presents the steps sequentially, although the process is highly iterative with multiple loops.

We used scientific databases and publicly available internet sources in our literature survey. We communicate with the building owners and system experts through face-to-face interviews and email.

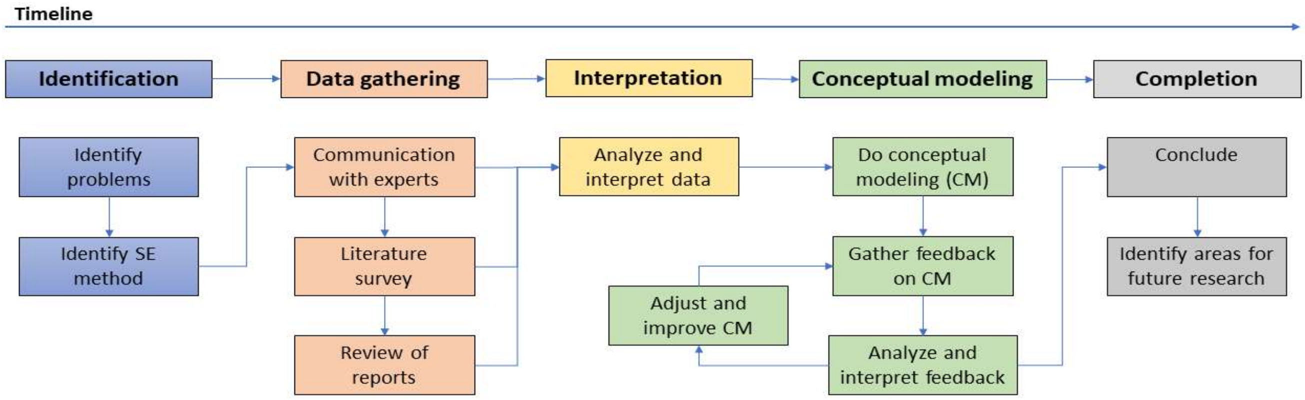


Figure 3: Research design

Energy storage potential in Norway

We have investigated the production and consumption of energy in Norway over two years, to find the energy surplus in the Norwegian power grid and thereby the potential for energy storage. The diagrams build on data from Nord Pool and Statnett. Nord Pool handles most of the power demand and supply in Norway, which is Europe's leading power market (NordPool, 2020).

In Norway, hydropower accounts for more than 95% of the total power production, and the annual production was 141 TWh in 2018 (Energy facts Norway, 2019). The storage capacity is high, as Norway has half of Europe's hydroelectric reservoir storage capacity. More than 75% of the electricity production is flexible. This flexibility allows for rapid change in electricity production, increasing or decreasing as needed.

The energy balance is the relationship between production and consumption and indicates whether there has been a surplus in the energy system in a particular year or not. The surplus can vary from year to year. Figure 4a shows the electricity production and consumption. There is an electricity surplus in Norway during the summer. In the winter months, when the consumption is higher than the production, Norway will import energy.

Figure 4b shows the electricity surplus in the Norwegian energy system over two years. This surplus electricity can be stored if the infrastructure is available. We estimate the energy surplus to 11 TWh in 2018, and 4 TWh in 2019.

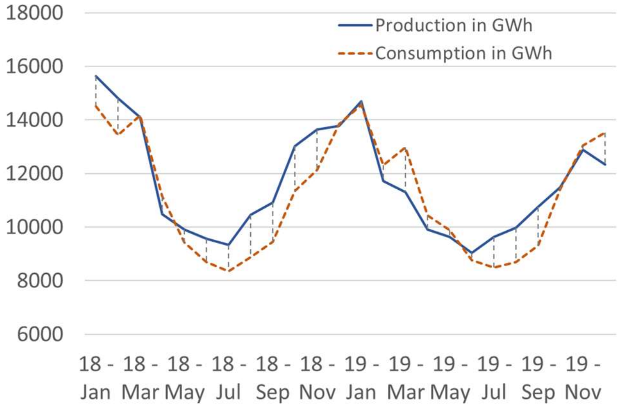


Figure 4a: Electricity production and consumption

Figure 4b: Energy storage potential (GWh)

Energy storage technologies

In this section, we briefly describe various types of storage systems with their advantages and disadvantages. We investigate the more developed and mature technologies, together with concepts that the decision-makers in Kongsberg already investigates and evaluates for use in the municipality.

Classification of energy storage systems. Figure 5 classifies the most common storage systems according to the form of energy used (IEC, 2011). In this study, we will investigate pumped hydro energy storage, hydrogen storage, and thermal energy storage in salt, in addition to a short evaluation of batteries as short-term energy storage.

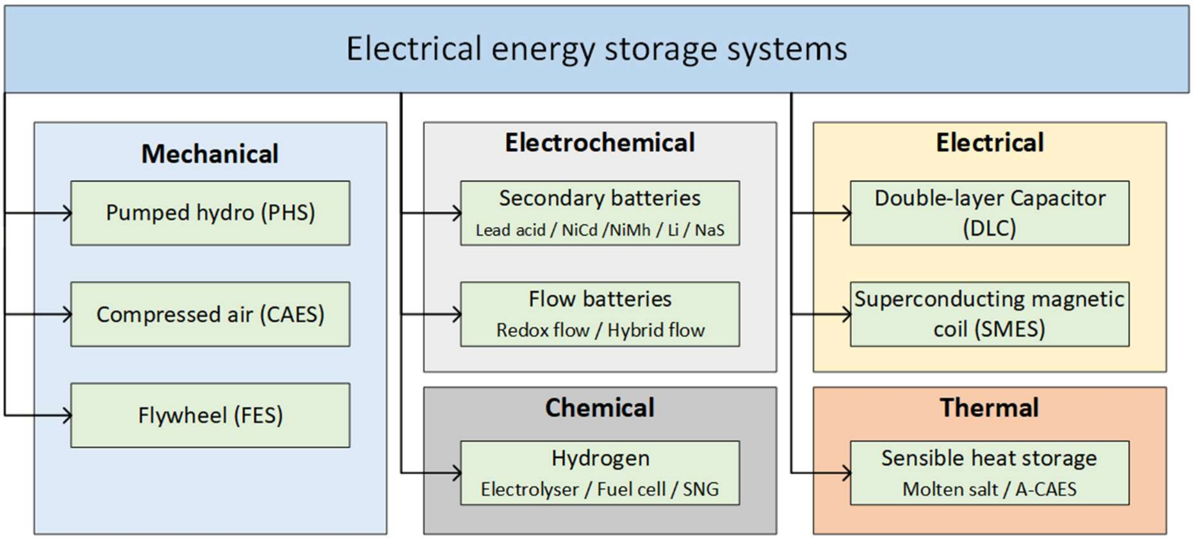


Figure 5: Classification of storage systems

Batteries. Batteries are technically mature for use as short-term energy storage. Especially lithium-ion batteries are essential as storage technology for portable and mobile applications, such as electric cars. They have a high energy density and efficiency, typically between 95-98% (IEC, 2011).

Pumped hydro energy storage (PHS). The PHS system consists of two water reservoirs at different elevations, a pump, and a turbine. When there is a surplus of energy, the system pumps water from the lower to the upper reservoir (IEC, 2011). During periods of high demand, the water in the upper reservoir flows back down, powering a turbine with a generator to produce electricity.

PHS is ideal for long-term energy storage as the system has a high capacity and low self-discharge. It is also the most mature large-scale storage technology, making up most of the world's storage capacity today. Further, the system has high efficiency and a long lifetime (Deane & Gallachóir, 2016). However, there are also several barriers when it comes to PHS. Both the investment costs and impacts on nature are high, in addition to difficulties with the identification of locations with suitable topography.

Hydrogen storage. Hydrogen is a secondary energy carrier, where the main purpose is to use the excess electricity from renewable sources to produce hydrogen via water electrolysis. In an electrolyzer, electricity splits water molecules into hydrogen and oxygen. To generate electricity in times of demand is a fuel cell used. Hydrogen and oxygen react in the fuel cell, producing water, releasing heat, and generating electricity (IEC, 2011).

There are different approaches to storing hydrogen: as a compressed gas, as a liquid, or absorbed into metal hydrides. The use of metal hydrides as hydrogen storage reduces the need for high-pressure vessels and reduces the risk of pressure burst explosions. Metal hydrides will have a maximum operating pressure of 20 bar, while gas storage typically uses from 200 bar up to 1 kbar (Hystorsys, 2018). We elaborate on the metal hydride technology further in the case study on Vestsiden middle school.

The overall efficiency of the hydrogen system is low. However, it allows for the storage of large amounts of energy over greater periods, as an option for seasonal storage. Further, by utilizing the waste heat from the hydrogen system, will the overall efficiency increase.

SaltX Technology. SaltX is a Swedish company that has developed a technology for storing energy chemically in salt. The technology uses nano-coated salt to store energy. Through the separation of salt and water molecules, the system charges a "thermal battery." When the salt is uncharged, it is a mixture of salt and water. A reactor heats the salt to 500°C, the water evaporates, and the reactor charges the dry salt (SaltX Technology Holding AB, 2018). Salt can be stored at room temperature over a long period, from one hour up to six months. When there is a need for electricity, a condenser adds water to the salt, discharging it, and in a chemical reaction is steam released with a temperature of up to 450°C. The potential energy of the steam turns into kinetic energy powering a steam turbine, producing electricity. This system allows for long-term energy storage, where the energy content remains constant throughout the storage period. The technology provides a capacity of 500-600 kWh per ton of salt.

Conceptual modeling of the energy system

A conceptual model captures multiple perspectives and viewpoints. Multiple views are required to make a comprehensive model that is effective for reasoning. In the following, we model the system from five alterative perspectives; drivers and needs, key performance parameters, PESTEL, functional flow and component models. We apply the models to a case and develop an overall conceptual model for an energy system.

Decision-makers drivers and needs

In our study, it is essential to know the needs and drivers of the decision-makers in the city Kongsberg. The decision-makers will typically be the politicians in the municipality.

The drivers forcing change are the drivers behind this study. We have derived the drivers and needs from the municipality's strategy and goals for the future, in addition to global objectives such as the UN Sustainable Development Goals and the Paris Agreement. Table 1 identifies the drivers.

Table 1: Drivers of the decision-makers

Drivers	Rationale
Global warming and sustainability	The vast amounts of greenhouse gases released into the atmosphere, cause climate change and the atmospheric temperature to rise, which has catastrophic consequences for life on earth. By taking a sustainable approach to new developments, we can contribute to limit global warming (European Commission, 2019).
The world's energy problem: *Renewable energy and intermittency*	The increased focus and dependence on renewable energy lead to various sorts of challenges. The main challenge is the problem of intermittency. Energy storage is essential if we are to rely only on renewable energy in the future.
Kongsberg as a "technology city"	Kongsberg is, and wish to continue to be, a technology city. This wish appears both in their overall vision and in goals for the coming years. One of the municipality's goals towards 2030 is to make the use of new technology evident for both the city's inhabitants and the industry. The city is known for being a test arena for innovation while they, at the same time, wish to build a sustainable society (Kongsberg kommune, 2019a).
Municipal buildings as plus houses	The municipality has built new schools in Kongsberg as plus houses that produce energy. It is, therefore, a need for energy storage. Vestsiden middle school is a pilot installation with energy storage in metal hydrides.

As seen in Figure 1, the needs and concerns of the decision-makers are related to both the executors as well as the experts. At the same time, the decision-makers have to consider signals from society. Table 2 identifies the needs.

Table 2: Needs of the decision-makers

Needs	Rationale
Independence from fossil fuels	The municipality needs new solutions that are independent of fossil fuels, to reach its goal to become a zero-emission society by 2030 (Kongsberg kommune, 2018).
Guaranteed supply and flexibility	We need energy storage to cope with the variations in supply and demand from renewable energy. A renewable energy system is possible if we can solve the problem of intermittency. Energy storage must provide energy when there is a demand to guarantee the supply.
Economic benefits from affordable solutions	For the energy storage systems to become feasible to install and operate, they must add economic benefits for the municipality. Capital Expenditures (CAPEX) and Operating Expenditures (OPEX) are measurements on the acquisition and operating costs (Maverick, 2020). CAPEX is the funds used by a company to acquire, upgrade, and maintain major physical goods or services, which they will use for more than a year. OPEX, on the other hand, represents the day-to-day expenses required to meet the ongoing operational costs in a company.
Regulatory compliance and low impacts on nature	The concepts for energy storage must comply with relevant laws, policies, and regulations. Compliance is essential to ensure that the concepts are safe and without risk for the society and the inhabitants in the municipality. We should also strive to achieve low impacts on nature and minimize the ecological footprint.

Key Performance Parameters

To fulfill the needs of the decision-makers, we look at the concepts for energy storage and their Key Performance Parameters (KPP). We use capacity, efficiency, CAPEX, OPEX and environmental footprint as KPPs to evaluate and compare the different storage concepts.

The decision matrix in Table 3 provides the KPPs. We define OPEX as 2% of the investment cost when exact data are not available. Further, SaltX Technology Holding has not given the operational cost, only the Levelized Cost of Storage (LCOS). The numbers are not exact and are only for informational purposes. The values can rapidly change as technology develops further and improves.

The KPP in Table 3 shows that the storage technology is neither viable nor profitable, as the investment cost is high due to immature technology.

Table 3: Decision matrix

	Key Performance Parameters					
	Capacity	Efficiency	CAPEX	OPEX	Discharge time	Footprint
Hydrogen Storage (Compressed Gas)	1 - 1000 GWh[1]	40% (el.)[1]	> 5000 \$/kW[2]	2% invest:[3] > 100 \$/kW	1 h - 1 month[1]	Small
Pumped Hydro Storage	0.1 - 10 GWh[1]	75-85%[3]	900-1650 \$/kW[3]	2% invest:[3] 18-33 \$/kW	10 h - 1 month[1]	Large
SaltX Tech.[4]	10 MWh	33% (el.) 90% (thrm.)	200 \$/kWh	*LCOS:* 0.15 \$/kWh	4-36 h	Small

[1] (Moore & Shabani, 2016), [2](Kharel & Shabani, 2018), [3](Deane & Gallachóir, 2016), [4](SaltX Technology Holding AB, 2018)

PESTEL

A PESTEL analysis is a method to analyze and monitor macro factors. The acronym definition is P for Political, E for Economical, S for Social, T for Technical, E for Environmental and L for Legal. The PESTEL analysis helps us identify the potential barriers for implementation and the consequences of the different storage solutions. Table 4 presents the macro factors identified for energy storage systems.

Table 4: PESTEL, Assessment criteria

Political - Feasibility - National goal compliance	**Economical** - CAPEX - OPEX	**Social** - Benefit for society - Potential harm (e.g. noise)
Technical - Maturity - Complexity	**Environmental** - Footprint - Impact on nature	**Legal** - National laws - Local regulations

Component and functional model

The component models of Figure 6a, b, c show the relationship between the physical elements of the three alternative storage technologies. Similarly, the functional models in Figure 7a,b,c illustrate what the different components of the system do, and how the different substances flow through the system.

The hydrogen storage models in this section are for compressed hydrogen gas as storage medium. An electrolyzer converts water into hydrogen, and a compressor pressurizes the hydrogen for storage in pressure tanks. The fuel cell converts the hydrogen back into water and electricity. The inverter transforms the electricity into alternating current prior to use.

We use the following notation in the models:

- Energy: E_{Sun} = solar energy, E_{In} = Energy in, E_{Out} = Energy out
- Electricity: El. (DC = direct current, AC = alternating current)
- Water: H_2O
- Hydrogen: H_2

Case study: Vestsiden middle school

This case study investigates the energy storage system at Vestsiden middle school. This pilot installation includes solar panel (photovoltaic) energy production, electrolyzer for hydrogen production, and seasonal storage of hydrogen in metal hydrides. Fuel cells generate electricity from the stored hydrogen in the winter season.

The school has a microgrid that connects to the public grid. The system consists of solar panels that provide the school with power. In addition to local battery storage, they have also planned for local hydrogen production and storage. The system allows for the storage of the excess solar energy as hydrogen during times of surplus. The stored energy, together with geothermal energy, will provide the school with power and heating in times of high demand and low solar production.

The system is a pilot installation and will be the largest of its kind with a storage capacity of 2800 kWh (Bredesen, 2019). The complete installation had an investment cost of about 15 000 000 NOK (Benum, 2020).

Bredesen (2019) simulated the energy demand at Vestsiden middle school during year with one hour time steps. We base the models in this case study on the simulated numbers. The focus of this study is the power production and consumption, heat production and consumption is not covered.

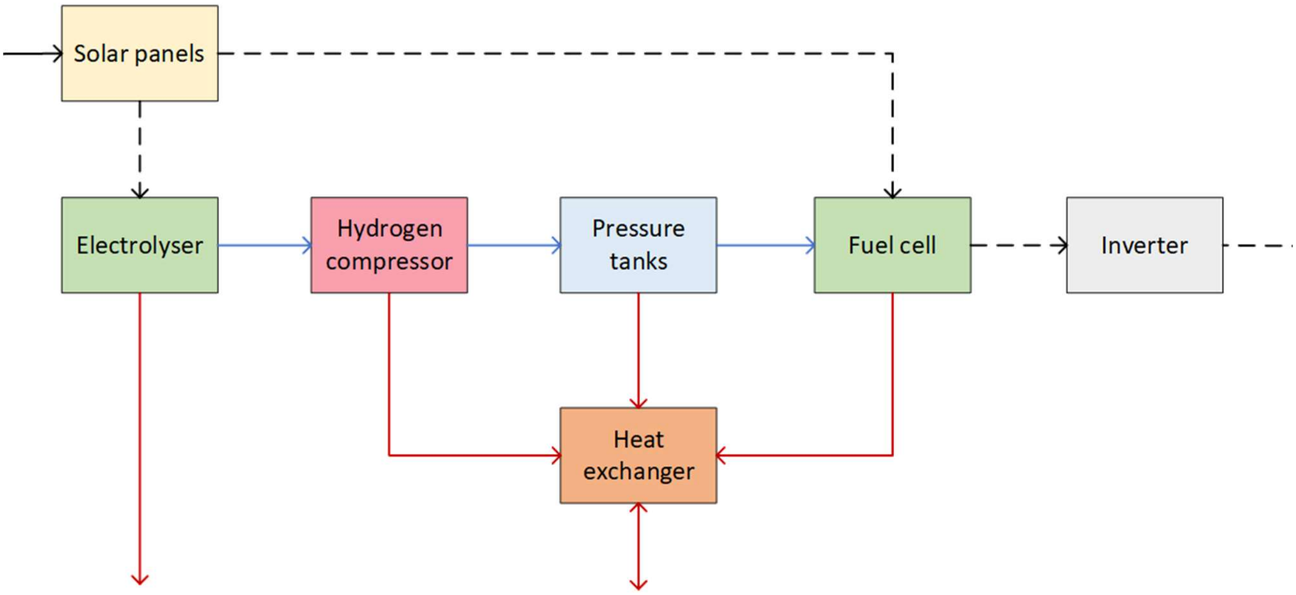


Figure 6a: Component model for storing hydrogen as a compressed gas

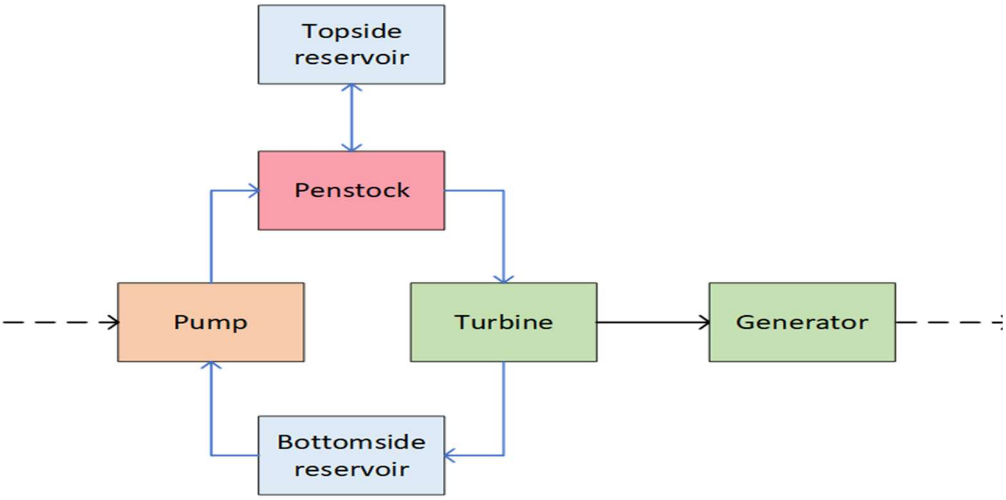


Figure 6b: Component model for pumped hydro systems

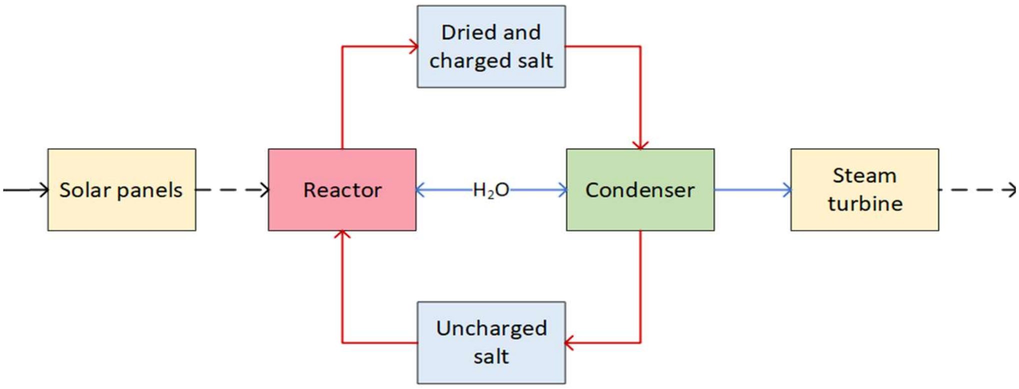


Figure 6c: Component model for SaltX storage system

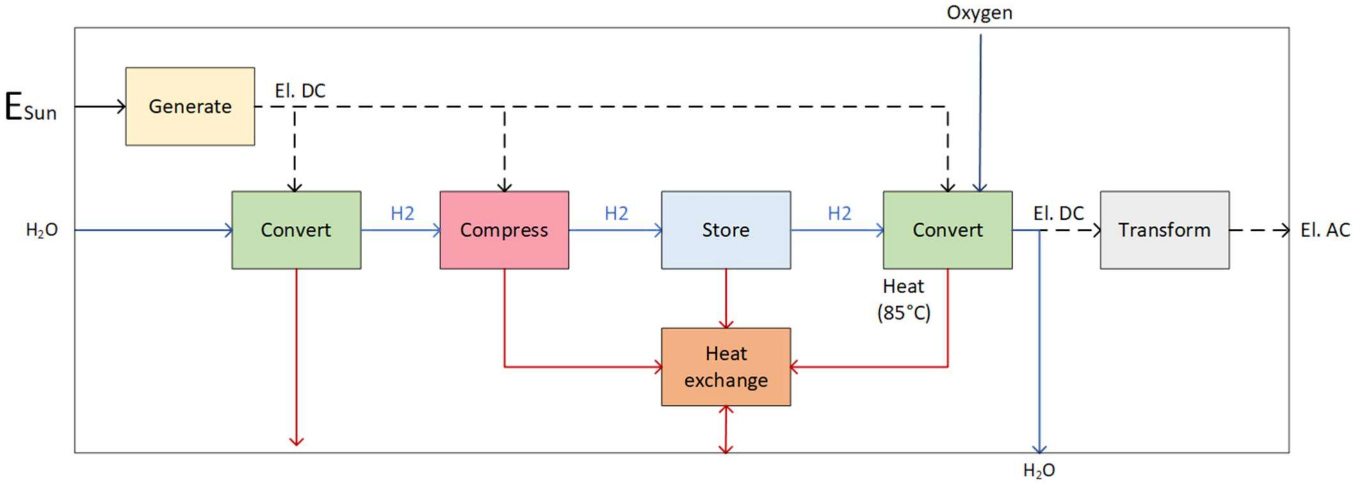


Figure 7a: Functional model for storing hydrogen as a compressed gas

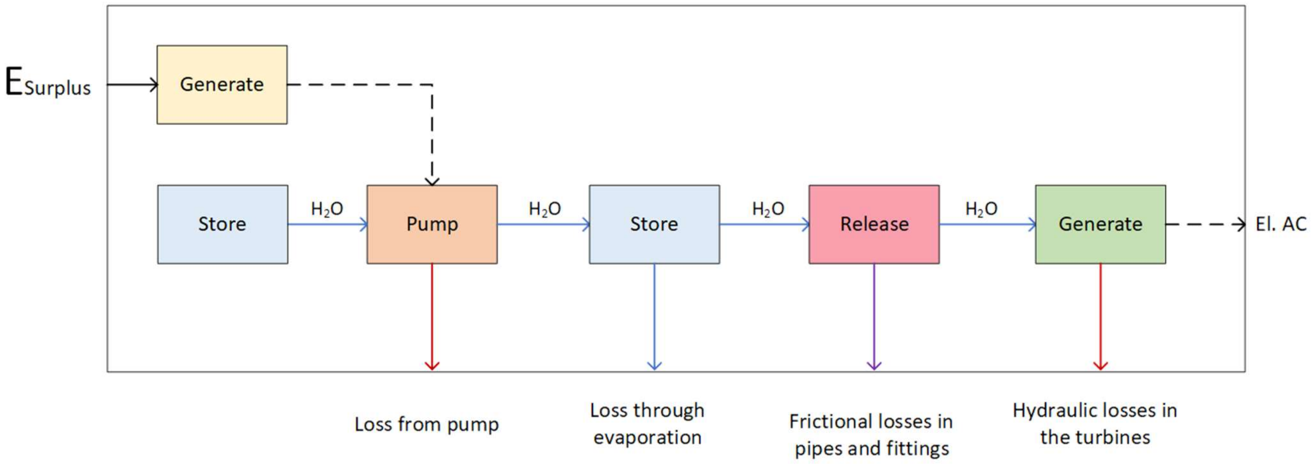


Figure 7b: Functional model of pumped hydro storage

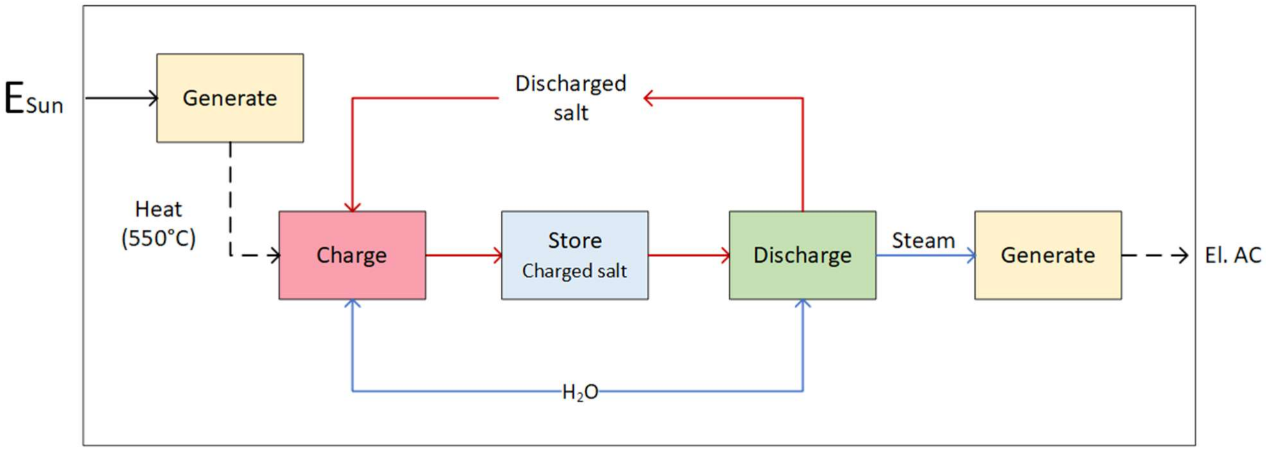


Figure 7c: Functional model of SaltX energy storage

Storage potential

Bredesen (2019) calculated the power demand of all larger energy carriers in the building and simulated the annual solar power production. We base the models presented in this case study on data from these energy simulations. The simulations map the power supply and demand every hour throughout the year. The values used in this study are the gross power demand, which is the building's actual power demand, including all losses and efficiencies in the systems.

Figure 8 compares the consumption (demand), production (supply) and energy storage potential during the year. When the production of solar energy is higher than the demand for power, there is a potential for energy storage in the system. The orange bars in the diagram illustrate the amount of energy that we potentially can store. The total potential for storage in hydrogen is 114.4 MWh. The potential energy storage is mainly available in the summer months.

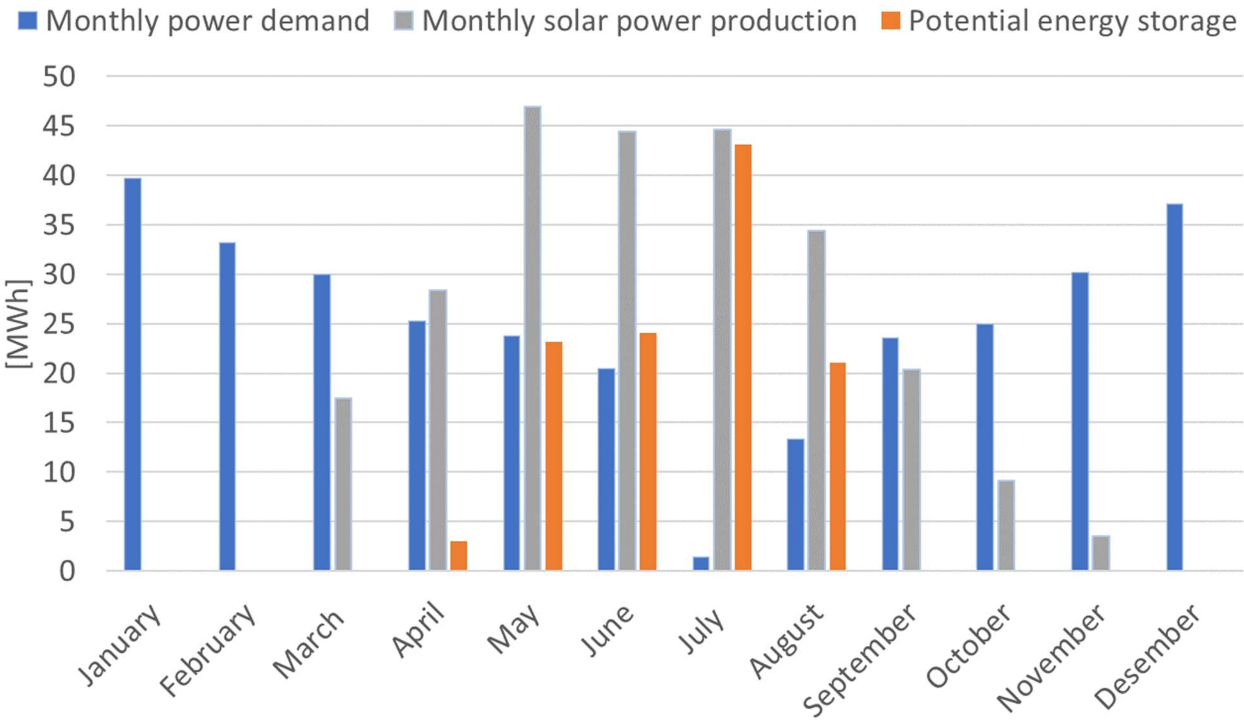


Figure 8: Production, consumption and potential for energy storage

Storage technologies

In this section, we describe basic principles of the different energy storage technologies. The component model illustrates the relationship between the elements. The functional model in illustrates the process.

Vestsiden has a battery bank with a total capacity of 61.2 kWh. Surplus energy from the solar panels charges the battery bank. When the batteries are fully charged, the control system will direct the excess energy to storage.

Figure 9 and 10 show the pilot installation at Vestsiden. A proton exchange membrane (PEM) electrolyzer produce hydrogen from water and electricity. The electrolyzer splits the water molecules into hydrogen and oxygen. The electrolyzer at Vestsiden is capable of receiving 20 kW of power

(Bredesen, 2019). However, the process of producing hydrogen requires high pressure, and it generates heat. Bredesen has calculated this heat loss to 8.1 kW, in addition to 0.75 kW of heat lost to the surroundings. The output of the electrolyzer is therefore hydrogen with an energy content of 11.15 kW. This output gives the electrolyzer an overall energy conversion efficiency of 56%.

Metal hydrides store the hydrogen at a lower pressure and temperature, which is safer compared to hydrogen stored as a compressed gas (Hystorsys, 2018). The process causes heat dissipation when the metal absorbs the hydrogen. In addition, heat is required to release the hydrogen from the metal. Storage in metal hydrides is an innovative way of storing energy and the plant is a pilot installation.

Kongsberg Kommunale Eiendom (KKE) will initially invest in 120 bottles of hydrogen, which has the capacity of storing 84 kg of hydrogen. The 84 kg of hydrogen contains 2800 kWh of stored energy (Bredesen, 2019).

The fuel cell is a PEM fuel cell, operating much like the PEM electrolyzer. When feeding hydrogen into the fuel cell, the fuel cell splits the molecule into hydrogen ions and electrons, making an electric current. The hydrogen ions bind with the oxygen in the air, making water vapor the only bi-product.

Hydrogen equivalent to 44.6 kW feed into the fuel cell. 24.6 kW of heat dissipates and the electricity production is 20kW. The fuel cell energy conversion efficiency is 45% (heat dissipation not included).

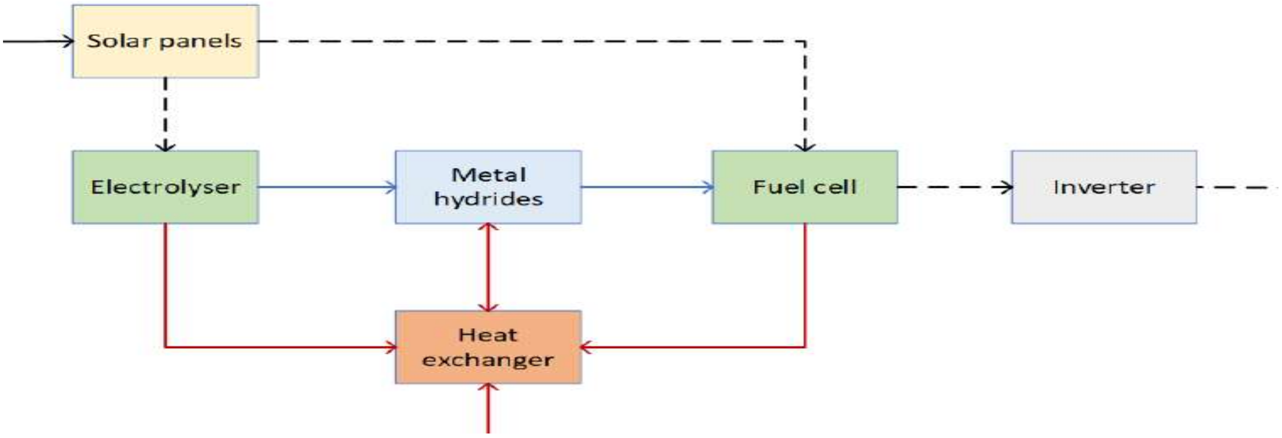


Figure 9: Component model of hydrogen storage in metal hydrides

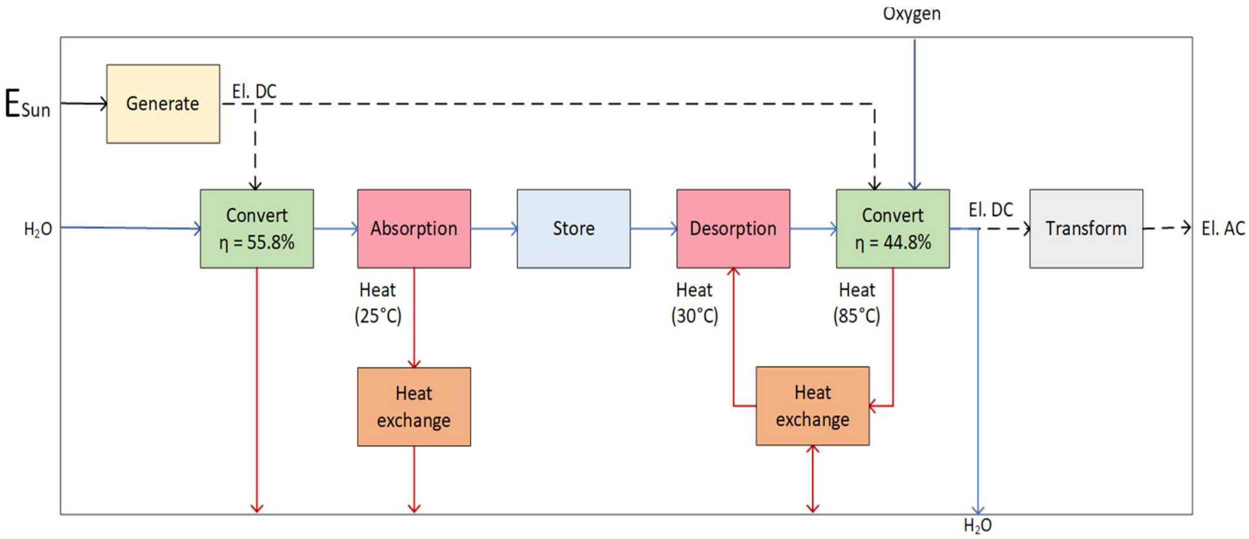


Figure 10: Functional model of hydrogen storage in metal hydrides

Energy balance

Figure 11 shows the energy balance for one year for Vestsiden. The input energy comes from solar energy and the grid. The power demand at the school consumes about half (135MWh) of the produced solar power directly, while we store the remaining (114MWh) in hydrogen. Despite reasonable component efficiencies, a large amount ((50+35)/114=75%) of the potential energy storage is lost in the energy storage process.

Figure 12 and 13 shows the monthly energy balance for May and October. We lose significant parts of the surplus solar energy to heat in the storage process. We can use the heat in the room heating to increase the overall efficiency of the system if the heating system allows for low temperature heat sources. The functional model (Figure 10) identifies the heat sources.

Case study summary

We aim to utilize as much as possible of the produced solar power. By having a system such as hydrogen storage, we can store the renewable energy that we otherwise would have lost. The models visualize the impact of the different component efficiencies. With increased efficiency, the heat loss decrease and the energy output increase.

The electrolyzer and fuel cell are well-known technologies for producing hydrogen from renewable sources and later converting back to electricity. The models show where we lose energy. The models also show the impact of the different elements on efficiency and the utilization of surplus energy.

Discussion

The energy balance diagrams of Figure 11, 12 and 13 provide answers to several vital questions, such as how much energy the building consumes and for what. It also gives the amount of solar power for storage, how large the losses are, and how much electricity comes from the grid.

To determine how well conceptual modeling has contributed when communicating and evaluating the systems for energy storage, we evaluated the models with the engineer designing the energy system at Vestsiden. The engineer found them clear and easy to understand. As an expert, the energy engineer has the insight to understand the system. The models give a good overview of the flow of energy through the system. Further, the models are a basis for investigation on how the efficiencies in the system affect the output energy and how we can improve the overall efficiency.

We discovered that it important to find a balance between how detailed and how simplified the models should be. The goal is to give a clear and useful representation of the systems. It is essential to find the correct level of simplification so that the experts can use the models to evaluate options and communicate these options to the decision-makers.

A weakness in our models may be that we have not sufficiently covered the heat utilization. We saw from the energy balance diagrams that we lose 75% of the stored energy as heat. If we utilize the heat generated by the electrolyzer and fuel cell as room and water heating, the overall efficiency will increase significantly. Reusing the heat requires that the system generates heat at the same time as there is a demand. In the winter, the solar production is low and there is a need for both electricity and heating. It is more likely that we can reuse the waste heat from the fuel cell than the waste heat from the electrolyzer. The process of electrolysis typically takes place in the summer when the heat demand is low and the surplus energy production is high.

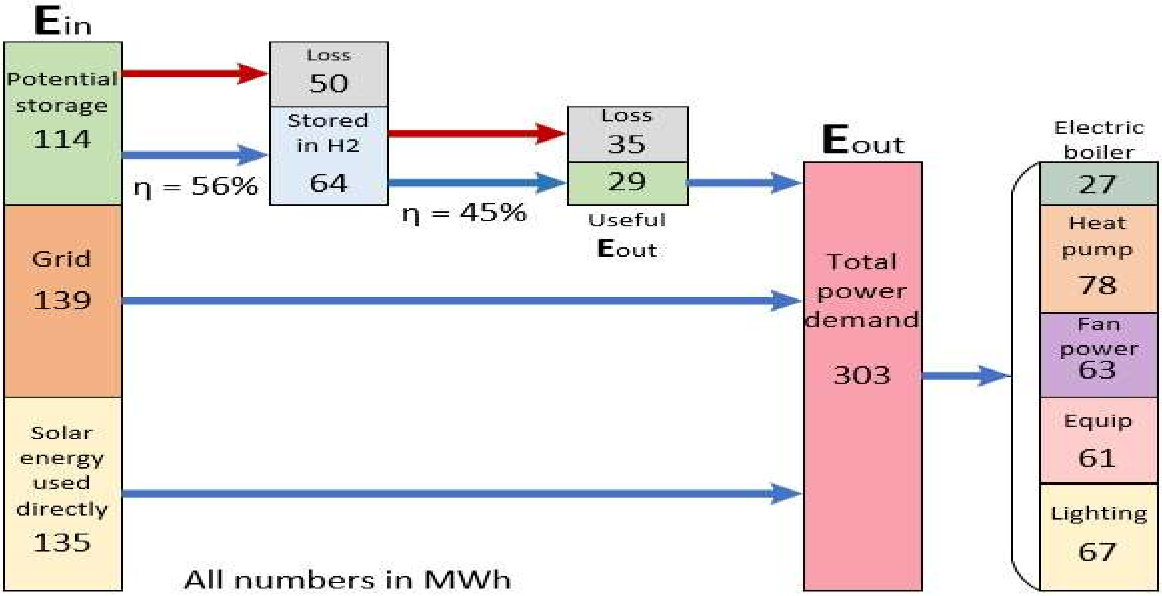


Figure 11: Annual energy balance

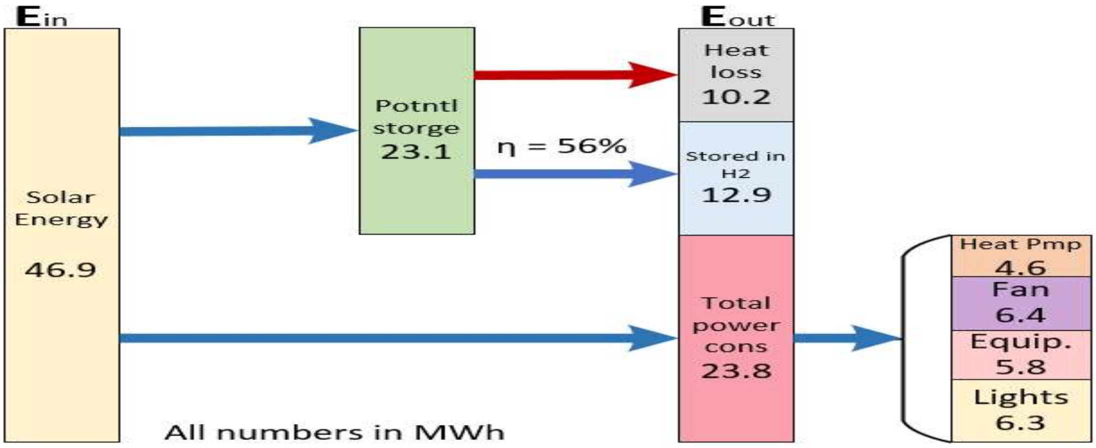


Figure 12: Monthly energy balance in May

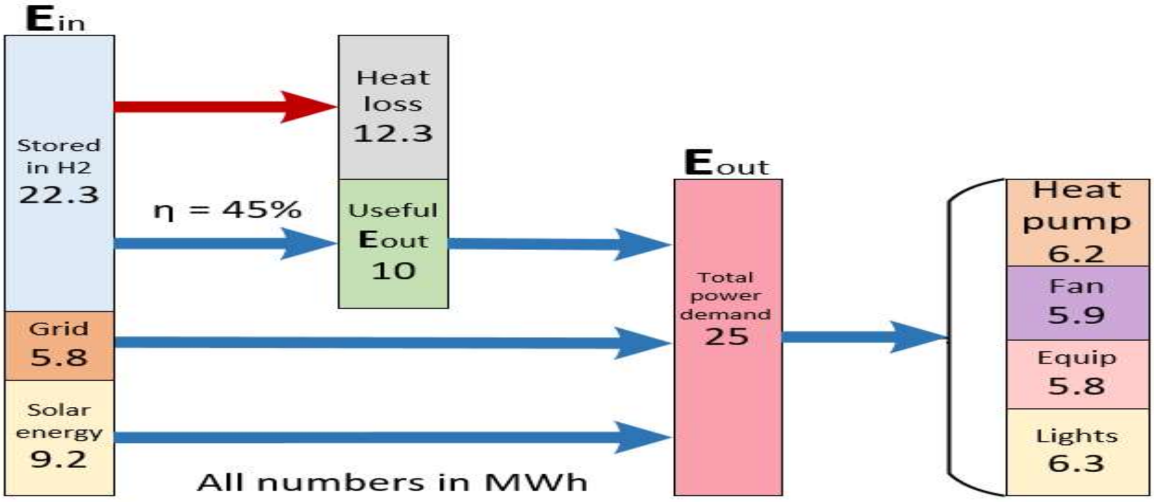


Figure 13: Monthly energy balance in October

Conclusion

Intermittency is the largest challenge in a grid exclusively based on renewable energy. A solution to mitigate intermittency is to store the excess renewable power for use when the electricity demand exceeds supply. Energy storage allows for a continuous supply of energy and allows grid flexibility.

We use conceptual modeling when selecting the most suitable and technically feasible alternative for energy storage. Conceptual modeling helps identify when and where we lose energy, how we capture and utilize this loss, and where we must improve the system. The models give a good overview of the flow of energy through the system. This overview can contribute to the improvement of the efficiency in the system.

A weakness in the conceptual modeling for the hydrogen system is that we have not sufficiently emphasized the possibilities for utilization of the waste heat. The lack of emphasis is due to oversimplification of the system. The reuse of waste heat in hydrogen storage systems will increase the efficiency and make hydrogen a more economically viable storage solution.

Simple visualization of the energy storage concepts using conceptual modeling requires a comprehensive study of the technologies. To give a useful and valuable representation of the concepts is it essential to find a balance between how detailed and how simplified the models should be.

Conceptual modeling in an energy storage perspective has worked effectively and successfully. However, it is challenging to find the right level of simplification without eliminating other possibilities that the system can offer. The strength of the models is that one can quickly get an understanding of the concept and get an overview of the main features of the system.

Conceptual modeling contributes to a clear and useful representation of the systems. We can use these simplified models to communicate the system behavior at a high level. Our work indicates that the models help support the technology selection process for energy storage systems.

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Biography

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Gerrit Muller, originally from the Netherlands, received his master's degree in physics from the University of Amsterdam in 1979. He worked from 1980 until 1997 at Philips Medical Systems as a system architect, followed by two years at ASML as manager systems engineering, returning to Philips (Research) in 1999. Since 2003, he has worked as a senior research fellow at the Embedded Systems Institute in Eindhoven, focusing on developing system architecture methods and the education of new system architects, receiving his doctorate in 2004. In January 2008, he became a full professor of systems engineering at University of South-Eastern Norway in Kongsberg (USN), Norway. He continues to work as a senior research fellow at the Embedded Systems Innovations by TNO in Eindhoven in a part-time position. Since 2020, he is INCOSE fellow and Excellent Educator at USN.