Decentral Energy production and integration in the Stavanger region

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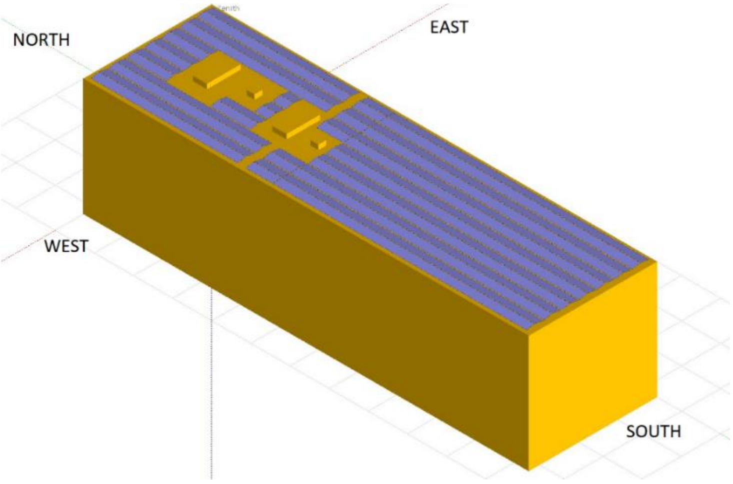
A techno-economic case study of Stavangerregionen Havns and Risavikas solar production potential and its contribution to the local energy challenges within the Elnett21 project



Master Thesis by

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Abstract

This thesis explores the solar production potential of Stavangerregionen Havn and Risavika and its possible contribution to the local energy challenges within the Elnett21 projects, that arises with the transport electrification strategy from the Norwegian government. The aim of this study is first to show the solar electricity generation potential for the given buildings and then investigate an economic long-term performance of those projects. Furthermore, will be explored how the integration of local produced electricity can be supported by battery storage systems.

The thesis uses a Mixed-Method approach which gives the option to explore qualitatively the possibilists and challenges of the concept of system decentralization, decentral solar production and battery storage. Additionally, is through the utilisation of the K2 and PVsyst software the simulated electricity generation potential explored on which bases the quantitative analysis and economic evaluation is executed.

Our analysis shows that Stavangerregionen Havn and Risavika have great electricity production potential which could be utilised. Furthermore, gives the economic long-term evaluation a positive output for the Ferry-Terminal as main case study object.

We concluded that through the development of local generated solar electricity and the utilisation of battery storage significant contribution towards Elnett21 and the challenges are possible. Dependent on the size of future solar production and battery storage capacity can the contribution be bigger or smaller.

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All for Nora

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Abbreviations

BOS	-	Balance of System
BTM	-	Behind-the-meter
CdS	-	Cadmium sulphide
CdTe	-	Cadmium telluride
CIGS	-	Copper Indium Gallium Diselenid
CPV	-	Concentrator Photovoltaics
DHI	-	Diffuse Horizontal Irradiance
DMS	-	Demand Side Management
EArry	-	Effective energy at the output of the arry
ESS	-	Energy storage system
EU	-	European Union
EV	-	Electric vehicle
GHG	-	greenhouse gases
GHI	-	Global Horizontal Irradiance
GRAMMS	-	Good Reporting of A Mixed Methods Study
HSS	-	Home storage system
IAM	-	Incidence Angle Modifier
ISS	-	Industrial storage system
LCOE	-	Levelized cost of Electricity
LCO	-	Lithium cobalt oxide
LFP	-	Lithium iron phosphate
LMO	-	Lithium manganese oxide
LSS	-	Large scale storage system
MLP	-	Multi-Level perspective

NaS - Sodium Sulphur

NBBL - Norwegian national housing association

NCA - Lithium nickel cobalt aluminum oxide

Ni-Cd - Nickel Cadmium

NI-MH - Nickel Metal Hydride

NMC - Lithium nickel manganese cobalt oxide

NVE - Norwegian Water Resources and Energy Directorate

O & M - Operation and Maintenance

POM - Placed On the Market

PV - Photovoltaic

R&D - Research and Development

SNM - Strategic Niche Management

SPS - Solar Photovoltaic systems

TM - Transition Management

V2G - Vehicle to grid

Units

Co$_2$ - Carbon-Dioxide

$/t - Dollar per tonne

€ - Euro

€/ kWh - Euro per kilowatt hour

€/ wp - Euro per watt peak

GWh - Gigawatt hour

KVA - Kilovolt ampere

Kg CO$_2$- eq/kWh - Kilogram Carbon-Dioxide equivalent per kilowatt hour

KW - Kilowatt

kWp - Kilowatt peak

MW - Megawatt

MWh - Megawatt hour

NOK - Norwegian Krone

NOK/ wp - Norwegian Krones per watt peak

t - tonne

TWh - Terawatt hour

Wh/ kg - Watt hour per kilogram

1. Introduction

The ongoing debate and increasing awareness of the current climate crises have spread further within society, industry, and politics. This has led to the development of new strategies on how a more sustainable future society can and should look. In addition, the signing of the Paris Agreement across the world has shown that countries must be more engaged and act more determined to hold the agreement. One key element thereby is the reduction of greenhouse gases across the society and industry.

One crucial element in this debate is the question of how the future transport sector and societies mobility will look while in present times is heavily relied on fossil fuels. The transport sector is comprised of all the means of transportation that are globally in daily use. Private transport, public transport, plane, and boat transport are there the key means that must make substantial progress. Considerable progress is currently done within the private and public transport sector through the introduction of electric vehicles and electric bus fleets. Whereas development in heavy transport such as trucks, shipping or air traffic are notably hesitant.

This hesitance is related to three main challenges. Firstly, the availability of technology that could supplement the high energy density needed for ships and aircrafts. Secondly, the availability of infrastructure that would be able to provide that energy. Lastly, the availability of the energy itself is in many cases a factor that hinders such a transition towards more sustainable transport installation.

The country that noticeably has made improvements towards a more sustainable transportation in recent years is Norway with the huge support of electric vehicles. The political support and the almost abundant access to renewable electricity through hydropower gives the opportunity to pursue the restructuring of the transport sector in many stages. Such a restructuring and resulting reductions in Norway, where the transport sector accounts 2019 for 30% of the countries GHG could be significant contribution to their own targets (SSB, 2019). Those emissions targets are set to a reduction of 50% by 2030 outgoing from the 1990 emission level which are in line with the EU targets (Klimaavdelingen, 2020).

To pursue those targets, strategies connected to the electrification of the transport sector and society gain substantial assistance. The new transport plan for 2018-2029 gives the direction to establish “A transport system that is safe, enhance value creation and contributes to a low-carbon society” (Norwegian Ministry of Transport and Communications, 2018, p. 13).

For the regional level a strategy like this is a significant challenge for the present infrastructure. As a result of national and regional challenges plans emerge and projects are initiated from local actors to develop a reliable future system. One of these regional development projects is Elnett21 and part of the electrification development of the Stavanger region. The research case of this study Stavangerregionen Havn is a part of the Elnett21 project and a crucial element for this development. This thesis aims therefore to address the key research question: *How much can Stavangerregionen Havn and Risavika benefit from development of own solar production and installation of battery storage and contribute to Elnett21?*

1.1. Background of the Problem

A recent report from Energi Norge points out that the share of renewables within the whole transport sector is around 14% in Norway (EnergiNorge, 2020). Therefore, the transport sector still has huge potential in greenhouse gas reduction through renewable energy sources. Reduced or emission free transport will therefore need a comprehensive level of electrification of the whole sector from the charging of more electric vehicles, aircrafts, busses and ships. Hence, will demand for electricity in Norway and the grid load increase significantly.

The highest measured consumption in the Stavanger region is 1300 MW and could increase by 600 MW which corresponds to the same size of 120.000 homes according to Lyse Elnett (Elnett21, 2020b). With current utility patterns of the grid infrastructure and energy system it is, however, not possible to provide this extra energy and capacity. To avoid expensive upgrading of grid infrastructure and still build a smart future directed energy system, Elentt21 a large-scale demonstration project is launched (Elnett21, 2020c).

Elnett21 should demonstrate a robust future solution for emission free, electric transport and contribute to meet future energy demand from the Stavanger region. It should show that local incentives and regional cooperation can increase efficiency of energy consumption with smart steering, increase security of supply, increase the capacity of the grid without big investments for grid expansion (Avinor, 2019). Especially, the cooperation between the main consumption hubs, the Stavangerregionen Havn, Forus Næringspark, AVINOR and their partners Lyse Elnett and Smartly becomes important. Main action points of the cooperation are to increase short, locally traveled energy and electricity production, energy storage, smart distribution through micro-grids and develop new business models (Elnett21, 2020c).

New energy and electricity production are mostly related to the expansion Solar cell, local wind, and district heating from Lyse Neo. Energy storage will mainly be related to chemical or organic battery storage as from the local battery company Beyonder which is under development. These are produced with sand and woodchip which have a significant lower greenhouse gas footprint than commercial batteries (Elnett21, n.d.-a). Smart distribution and management of energy and electricity in and between the cooperation partners as model to more effective and optimal resource usage. Through this cooperation and smart system development, outdated business models are replaced or updated to a future-proof structure. Stavanger airport points out the goal to be self-sufficient with renewable energy. Sola & Forus Næringspark and its around 2500 businesses aim to be energy neutral within 2015 to shape a more attractive business environment. However, the main focus is on the utilisation of roofs through PV, increase supply security and shape flexibility (Elnett21, n.d.-a)

In case of Stavagerregionen Havn, the contribution in Elnett21 should be within smart charging infrastructure, Solar cell installations, Battery energy storage and a smart local micro-grid system to steer electric load (Elnett21, 2020a). Focus lies on PV infrastructure, large-scale battery storage and smart control for power levelling and efficiency increase. This should give the opportunity to increase own flexibility or sell it further as business model (Elnett21, n.d.-a).

1.2. Statement of the Problem

The problem statement for this thesis and project analysis is based on the background presented in the section above. Stavangerregionen Havn faces three main challenges connected to the transition of the transport sector right now.

- First the issue is related to overall availability of enough short-traveled electricity for the increasing demand especially during peak hours where the grid load is already high.
- Second the non-existents of storage capacity which could be used during higher electricity demand of the terminal building and electrification of ships, cars, and trucks.
- Third is Stavangerregionen Havn missing a smart steering system for charging and the distribution infrastructure.

All three problems are inherently important parts of the development towards a future directed system and contribution to Elnett21. This master thesis will investigate the first and second problem and concentrate at the potential of own local electricity production from Solar PV to reduce grid load in combination with battery storage. Based on that background, the thesis will address the following research question:

- *How much can Risavika and Stavangerregionen Havn benefit from development of own solar production and installation of battery storage and contribute to Elnett21?*
    - *What is the Solar electricity production potential for the given roofs and buildings?*
    - *What are the costs associated with the Solar PV system and integrated battery storage for the roofs and terminal building?*

1.3. Aim and Objectives of the Study

With focus on problem one and two of Stavangerregionen Havn, it is important to first do estimations and analysis of the energy demand and energy production potential of Solar PV. The projection of the Solar PV potential refers to all roofs that are owned by Stavagerregionen Havn. Estimation and analysis of energy consumption refers to the terminal building at Risaviaka owned and operated by them. From that point, it is necessary to investigate the economic profile from the study by looking into savings and the payback rate in the long run. Lastly, it is important to investigate the contribution of such an investment and system development for the region and the Elnett21 project.

1.4. Importance of the Study

This study gives Stavangerregionen Havn the ability to reveal their potential and opportunities resulting from own short-travelled electricity production and smart storage integration. The revealing of the self-sufficiency and contribution possibilities for Stavagerregionen Havn as demonstrator could be followed by other actors. This can build into a learning effect for other companies to act similarly if the results and feedback are positive. Revealing the potential helps to build a future system that can handle future tasks such as high energy demand, peak hours, secure operation, and create economic value. Through this study Stavangerregionen Havn can contribute and be part of the big cross sectoral cooperation of different companies. The decentralised energy generation and storage in this setup as pioneer regional development project can deliver valuable experience. Being part of this development such as in the case of Stavageregionen Havn a big role is the electrification of ships. Norway has planned to reach the amount of around 70 electric ferries within 2022 which will have a significant impact on local grid and energy flexibility. (Elnett21, n.d.-b). For ferries, cruise ships and industry shipping have been made already first land electricity connectors at Risavika and Stavanger center (Stavangerregionen Havn IKS , 2019). Furthermore, electricity will be needed for green hydrogen production as a consequence of the Norwegian and EU hydrogen strategy to decarbonise the maritime sector (Ministry of Climate and Environment , 2020).

1.5. Scope of the Study

It is crucial to break down the size of the study from global electrification aims to national, regional, and the local environment within the Elnett21 project in Stavager, Norway.

The Solar PV potential analysis will be done for the selected roof areas from the Stavangerregionen Havn. Energy consumption information will be related to the Terminal building at Risavika owned and operated by Stavangerregionen Havn. Other buildings owned by Stavangerregionen Havn have diverse tenants; therefore, access to consumption data is not possible. Those buildings and roofs will be presented through the simulated Solar PV potential and related cost estimations of the possible PV system. For those buildings and roofs the Solar PV potential estimation and related cost estimations of the resulting PV infrastructure will be presented, due to this limitation and battery storage sizing is not considered since the size is related to energy production and also consumption. In link to the terminal building, the battery storage integration and analysis becomes relevant since we will get information about simulated energy production and internal consumption data.

The Solar PV estimation will be based on approved technology which is available on the market. Other companies within the field will suggest different technical equipment like PV modules, inverters or battery storage they use. Those parts will vary from size, production potential, storage capacity and price. Companies often have agreements with producers and can provide discounted prices due to large scale purchases. This study will not have access or use this data and will therefore list prices which are freely available. The costs and economic evaluation of this study will; therefore, be more conservative, whereas an established supplier will present lower costs and different equipment than this study does. This will have the effect that the payback time for investments in a Solar PV system and battery storage of this study will be higher compared to possible offers from industry.

This study will not cover energy generation other than Solar PV since the focus lies within the idea what the contribution of Solar PV can and could be. However, it is acknowledged that for a future system the focus should be on the use of various energy sources and not to be dependent on just one. Due to the focus on Solar PV systems and electricity production the storage technology is considered in this research electro-chemical battery storage and not heat or other storage types. Batteries are fast respondents which is an important factor when it comes to peak shaving and grid balancing.

1.6. Outline of the research study

Chapter 1:

Addresses the introduction, background of the thesis, the problem statements for the thesis and presents the research question. With the aim to give an overview and introduction on the literature and case study. Furthermore, is the importance of the study and its scope addressed.

Chapter 2:

Chapter two presents first the concept of decentralization and its importance for the future energy and grid development. Additionally, are the benefits and challenges of decentralized Solar PV and battery system storage in a qualitative review explored to support the decision why those two technologies are utilised.

Chapter 3:

The third chapter presents the theoretical background why transition and development projects like Elnett21 are important. Furthermore, is explored the role and importance of political support, public support and global pressure to execute a transition project and challenge the present system through new strategic innovations.

Chapter 4:

This chapter addresses the research methodology and Mixed-Method approach used for this thesis. Moreover, are the study sides presented and how the quantitative data will be collected and analysed. Additionally, are assumptions and limitations concerning the data collection and evaluation processes addressed.

Chapter 5:

Chapter five presents the findings and challenges of the research and analysis with a part on the K2 modulation and PVsyst simulation. Furthermore, is the terminal consumption and costs data evaluated, which leads into the last section of economic project cost and economic long-term analysis.

Chapter 6:

Chapter six discusses the results in connection to the two sub-research questions and the key question of this thesis and its possible implications for Stavangerregionen Havn, Risavika and Elnett21. Additionally, is an outlook with suggestions for future research and investigations presented of topics that could be crucial in the further Elnett21 development.

Chapter 7:

The last chapter presents the concussion for this thesis its findings, limitations and long-term opportunities given through the exploration of Solar PV and battery storage systems.

2. Review of the Literature

The goals of Elnett21 are achievable considering future technological changes and development within the energy and electricity system. Especially, the development of decentralization of such infrastructure plays a key role in research. Therefore, the following chapter will guide through the idea of decentral energy and electricity production and consumption.

Most of the recent research based on decentralization focuses on the integration of renewable energies towards a 100% renewable energy system. The focus is to achieve a reliable and safe energy supply renewably powered. Main issues are the intermittency of sun and wind power and the challenge to build a system with these sources which fulfils the everyday needs of society and industry. One key point in this development is to generate local flexibility through a smart energy system so to take on the main issues of peak demand and excess energy production during low demand.

Even though Norway's electricity is covered to almost 100% renewable energy, local systems face big challenges due to the electrification of society and the transport sector. Therefore, regional, and local flexibility within the energy system is necessary which leads to the need of a more decentralised system in Norway. The starting point compared to a lot of research may differ in Norway. However, the issues of peak demand and long travelled electricity are the same as in other countries and will increase due to electrification of the transport sector and society.

2.1. Concepts towards sustainable development beyond decentralisation

Decentralization can be one of the key drivers towards a more sustainable society, industry, and biosphere. Besides decentralisation are three concepts of connectedness, integration, and prosumption elementary towards a system that provides sustainable energy development and utilisation (Khalilpour, 2019a).

Connectedness can be defined as the state of being joined or linked which society has developed through living together on cooperative groups and communities (Khalilpour, 2019a). The development of the internet and wireless communication possibilities has shaped a new level of global connectedness. These social and technological progresses and connectedness could be one of the most outstanding achievements from the industrial revolution. Connectedness gives huge potential of improvements of efficiency in physical-social networks, supply-demand management (Khalilpour, 2019a).

As our world can be seen as a completely integrated system our actions will have consequences. Especially by reaching the boundaries of the nine key earth system processes are motivation towards sustainability. The nine identified processes are: climate change, rate of biodiversity loss, nitrogen cycle, phosphorus cycle, stratospheric cycle, ocean acidification, global freshwater use, change in land use, atmospheric aerosol loading, and chemical pollution (Griggs et al., 2013). The goal is to avoid the so-called Callendar effect which refers to the integration phenomena. Where increased CO_2 concentration distributes vital earth system processes and passes this on to the Earth by warming it which affects other processes (Khalilpour, 2019a). All nine Earth system processes are interconnected and therefore sustainable development progress is not acceptable outside one of the boundaries. One step towards less violation of boundaries could be becoming a prosumer.

A prosumer is derived from an end consumer and energy system being a producer and consumer at the same time. Today’s supply chain is strongly based on the structure to be producer or supplier and the consumer stands on the demand side (Khalilpour, 2019a). Due to this often-one-sided relation demand-side management (DSM) grow as a research field to study this relation especially in the energy field to ensure sufficient resources during peak demand or low production capacities. The level of one-sided centralization reached is however, not optimally efficient today or in the future. A prosumer is, however, flexible and able to produce energy or electricity and consume it in totality or in some degree at the same time. Prosumers are a part of decentralizing networks towards a more sociotechnical optimum, by taking over some production task and increasing flexibility (Khalilpour, 2019a). Prosumers reached great importance when it came to research and development of decentral networks and utilisation of solar generated electricity. However, decentralisation is just a step within the development to the future energy and electricity system we need.

Centralization and decentralisation have their foundations within politics and governmental structures within the French revolution and developed in the 20th century further (Khalilpour, 2019a). Especially, through the second *Industrial Revolution* the development towards the idea of technological centralization and the aim of efficiency and higher revenues with *economy of scale* developed (Khalilpour, 2019a). It has created a sociotechnical connected world which is heavily centralized. This one-sided centralized network based on concentration and synchronization has a shortage when it comes to safety, robustness, and flexibility. Moreover, should infrastructure development work towards a decentralized but connected network as in *Figure 2.1.* shown. In the energy context a decentralised energy system could be characterised: "by small-scale energy generation units (structures) that deliver energy to local customers. These production units could be stand-alone or could be connected to nearby others through a network to share resources, i.e. to share the energy surplus" (Vezzoli et al., 2018, p. 25).

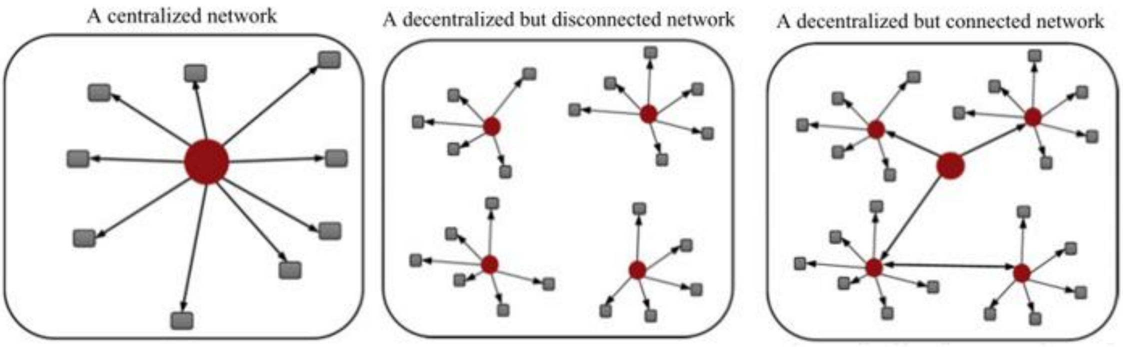


Figure 2.1. Central vs Decentral networks (Khalilpour, 2019a, p. 30).

The next step would be a development towards a distributed networks system. In the energy context a distributed energy system could be defined as:

> “small-scale energy generation units (structure), at or near the point of use, where the users are the producers— whether individuals, small businesses and/or local communities. These production units could be stand-alone or could be connected to nearby others through a network to share, i.e. to share the energy surplus” (Vezzoli et al., 2018, p. 25).

The main difference between distributed and decentral network can be found in the amount and size of small units to produce and share energy nearby. Along with those key developments and more decentralization must be the prosumer network mobilized to shape a system that is integrated and improves sustainability with the earth systems (Khalilpour, 2019a).

2.2. Benefits and barriers for decentralisation

It is important to emphasise that the focus in this study is on electrical systems and electrical decentralisation. The integration of other energy vectors is, however, crucial and will further increase energy efficiency and flexibility, but exceeds at this point the boundaries of this study. The expectations that decentralisation could have a huge impact were presented. More concrete does this mean that for example local or nearby energy production and distribution increases reliability and reduces distribution loses as this is often a challenge for energy plants far away (Vezzoli et al., 2018). Additionally, is decentralization connected with democratization of production and consumption, more self-conscious consumption behaviour and resulting from this DSM. This kind of active consumption increases the efficiency of the current system and providing therefore as well economic, operational, and environmental benefits. Less infrastructure development for grid upgrading saves resources and protects the environment (Strielkowski, 2020).

Through the participation of many actors can it cope better with individual failures since energy can come from different nodes and connections through local micro energy grid connections which increases the flexibility of the whole system. Especially this kind of flexibility is needed under consideration that the number of electric vehicles, buses trucks, planes and boats charging station is expected increase significantly. Distributed and smart energy systems as part of new infrastructure in fast developing regions are not just enabling efficient operation but improve the development of new market capabilities (Strielkowski, 2020).

> “Smart grids are an intelligent network for transmitting and distributing interactive communications across all components of the energy conversion chain. Smart grids connect large-, medium- and small-sized, decentralized generation units with consumers to create a single overall structure” (Strielkowski, 2020, p. 82).

Through smart grids a new level of connectedness and integration is possible which leads to more self-sufficiency and a two-way distribution of energy.

To achieve a good level of distributed and decentralized networks are especially energy and in many cases electricity storage technologies crucial, in many cases though connected with high costs (Khalilpour, 2019b). Adoption, sociotechnical interaction, and utilisation of local energy production can be hindered by insufficient technical competence and high complexity. Furthermore, are often economic high start costs a barrier for a wider distribution through the society (Vezzoli et al., 2018). Research highlights in addition that institutional disadvantages and regulations, social- cultural and environmental barriers hinder a wider diffusion on that technologies and infrastructure (Yaqoot, Diwan, & Kandpal, 2016). Solar power is the energy source most associated with decentralisation, integration, interconnection and presuming of energy. Which gives it high relevance globally but increasingly in Norway and in the large-scale experiment Elnett21.

2.3. Decentralized photovoltaic systems

Solar power is the most abundant source of renewable energies, available at any location with different values dependent on the distance to the sun. Even though Norway is internationally well known for its renewable electricity from hydropower the potential for solar power is not as low as often suspected. The development and installation as therefore experienced in recent years big growth (NVE, 2019b). The strategy reveals that this development is just the start towards the goals for 2040. *Figure 2.2.* highlights that three different scenarios are made where the lowest would result in an installed capacity of 4 TWh and the highest at 10 TWh until 2040.

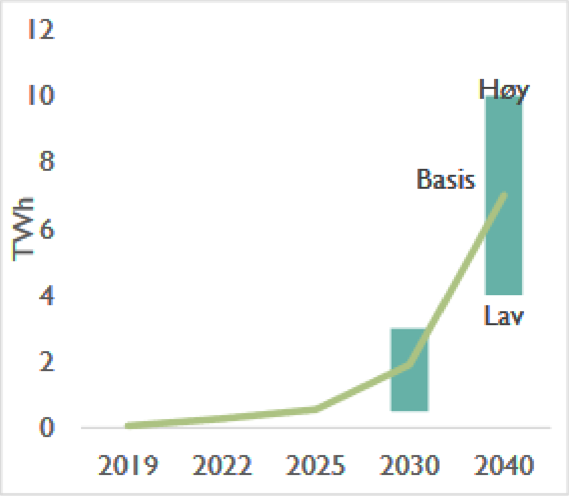


Figure 2.2. Solar development scenarios Norway (Veie et al., 2019, p. 22).

There are several Solar technologies, the two main technologies are solar photovoltaic systems which uses solar irradiation to produce electricity and solar thermal systems that use the sun's heat. In focus here are Solar photovoltaic systems (SPS) which convert sun energy by using solar cells. Solar Photovoltaic went through a huge development in the last 20-30 years. From the early starts in 1839 with discovering the photovoltaic effect until today is it possible to identify up to four generations of PV cells (Suman, Sharma, & Goyal, 2020).

The first generation is focused into monocrystalline and polycrystalline silicon and Gallium Arsenide cells. Silicon cells are dominant on the commercial market due to their general characteristics. Silicon is the second most abundant material in the earth crust, in general non-hazardous, nontoxic, long life and space efficient. A byproduct of crystalline production is silicon tetrachloride which are highly toxic. The efficiency of polycrystalline is lower compared to monocrystalline which are more expensive (Suman et al., 2020).

The second generation is focused on thin film technologies which aim to reduce high costs from the first generation. Cadmium telluride (CdTe) and Cadmium sulfide (CdS) cells showing efficiency numbers comparable to first generation poly-crystalline cells of 17%. Major problem is the highly toxic cadmium and limited tellurium availability. Copper indium gallium selenide (CIGS) cells show promising results however are costly due to higher manufacturing costs and struggling with a lifespan of around 12 years (Padoan, Altimari, & Pagnanelli, 2019; Suman et al., 2020).

The third generation derives from the development to increase PV cell efficiency by working with new materials like nanomaterials. Those got recently great attention due to their novel characteristics. The nano particles give more design flexibility, recombination losses are strong reduced, higher efficiency in ultraviolet light range and more resource efficient. Various cells struggling however with issues related to temperature stability, high topicality, low efficiency of 9-11% or high costs which hinder bigger commercial use. Most popular development from this generation are concentrator photovoltaics (CPV), organic and hybrid cells (Padoan et al., 2019).

The fourth generation emerged as flexible and low cost and strongly based on the idea of organic based nanomaterials like carbon nanotube and graphene due to their mechanical, chemical, electrical, and thermal properties in many diverse areas (Suman et al., 2020). Better known as “inorganics- in- organics” solar cells with good performance for environment and human health. The fourth generation combines inorganic and organic resources towards a better efficiency, high cost reductions and longer lifetime of nano structures into a new form of hybrid cells (Suman et al., 2020). Laboratory test have reached here a record high efficiency of 17.3% in 2018 (Meng et al., 2018). Commercialization will still take time, but it can then have huge potential especially because of the great ecological performance. The installation of decentral

Solar PV has benefits, drawbacks, and challenges. The following paragraph present the most important aspects.

2.3.1. Benefits

Solar PV can encourage active involvement of citizens and industry groups in the energy transition. Decentral energy systems are not restricted to its energy production instead shape opportunities for sustainable participation as consumer, investor, or social actor (Dahl, 2018, June 8). Active involvement in energy production and consumption distributes new responsibilities and places those responsibilities upon even more shoulders.

Increases participation, transparency, and legitimization for the transition is what society must go through. Small- or large-scale installation on roofs do not interfere with local environments and avoid or even can resolve conflicts with new local energy production which came up with the heated onshore wind discussion in Norway. Through the huge potential in participation, transparency for single actors increases and has the potential to shape more identification with the transition and its implementation locally and national. It generates a learning effect and commitment to the goals not just from private small-scale system owners, but through the whole industry and public sector who collectively acts. Actors who would usually not participate will more likely be inspired and learn from the others and take the same approaches if the experiences are positive.

The owner produced electricity gives the opportunity to reduce costs and dependency on the energy supplier. The bigger the installation side the lower usually the transaction costs compared to the total investment volume. Bigger installations have therefore a higher profitability compared to private small size PV projects. The profitability of an installation depends on the decision if an energy storage unit is selected. A big influence has as well the electricity price and the tariff system. Low electricity prices make own PV productions less profitable. Tariffs which demand extra costs during peak demands can be approached by smart

PV and battery management. Long time data show for Norway an electricity increases of 3-4% every year since 2012, which increases costs savings in the long-term. However, do show a 20-year forecast until 2040 as well a 40% increase or a 30% decrease in electricity prices (Tuv, 2019). Cost increases are as well expected for grid fees and consumption fees that improve the economic performance of decentral electricity production through Solar PV.

Through the development and installation of decentral PV systems local competencies will increase and have added value. It secures the local value chain through regional investments and income which gives local providers the ability to deliver sufficient service to the costumers. The whole country and society can profit from such a development and expertise aggregation, which can lead to getting specialists and new international operation possibilities (Bellini, 2020). Another benefit is that the local and even national development leads to a diversification of the energy sector which is today to 98% dependent on hydropower. Effects of dry summers and winters in the year 2018 and 2019 have shown how dependent electricity supply and prices are on full water reservoirs (Kleven & Leite, 2018, July 24). NVE has concluded from its latest research about the influence of climate change on hydropower supply the following: It will rain more in winter, the snow melt will be lower and summer will be less water available (Koestler, Østenby, Birkeland, Arnesen, & Haddeland, 2019). Even though the water amount will increase in total, so will be seasonal differences become more extreme as shown in *Figure 2.3*. bellow. Hydropower and PV could work thereby hand in hand since warm and dry summers are good production times for PV. Especially during this extreme situation solar has the ability reduce the need for hydropower.

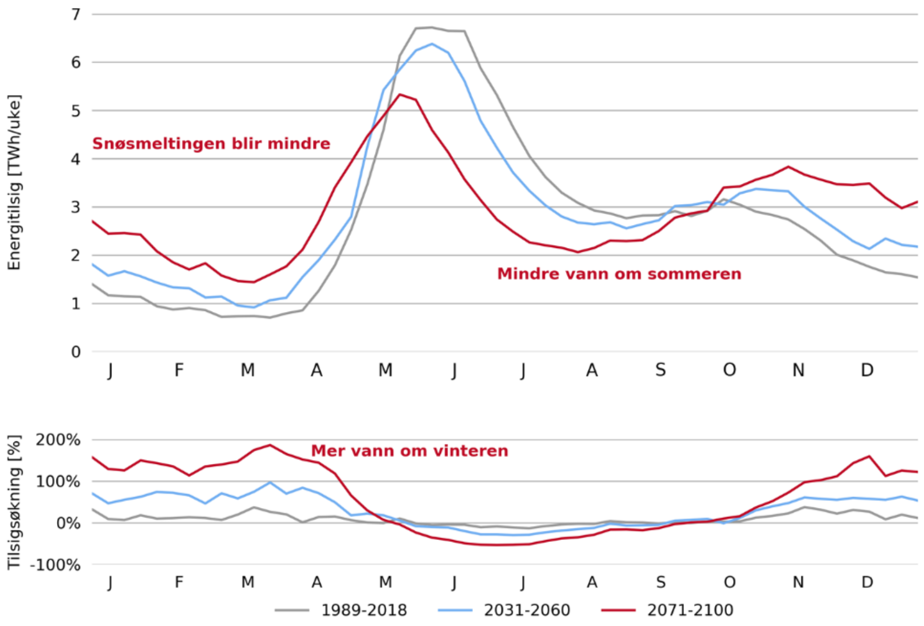


Figure 2.3. Norway's Future water supply profile (Koestler et al., 2019, p. 18).

Decentral systems increase the local production and increase the efficient use of energy resources. This results from the consumption of self-generated energy which has low transmission losses compared to other from long distances. Decentralisation helps therefore to avoid transmission losses and unload the grid to some percent to help in peak demand management (Kvalitetssjef, 2018b). Solar PV uses thereby efficiently unproductive infrastructure like roofs that is already in place and avoids huge local environmental impacts. Existing housing infrastructure has today a potential to charge up to 520.000 – 725.00 cars (Ask, 2020, July 15). These kinds of installations, therefore, help in urban regions where energy consumption is high and free space for new projects is scarce and huge grid expansion are economic inefficient. Remote areas which suffer of inefficient long-range infrastructure benefit from decentral energy development. The development of big energy infrastructure in relation to onshore wind installation and its biodiversity impact is an especially heated discussion now in Norway. A more strategic directed expansion of decentral PV systems could help then to reduce the need for unpopular and disputed wind installations (Ask, 2020, July 15).

2.3.2. Drawbacks and Challenges

Climatic conditions and changing weather conditions do influence the efficiency and function on PV modules and the resulting energy production. Especially weather changes have within seconds impact on the generated power, which creates significant output fluctuations (Marcos, Marroyo, Lorenzo, Alvira, & Izco, 2011). Therefore, the output will be a smoothing, balancing demand, and generation crucial for such a system. Furthermore, changes are difficult to forecast, control or regulate. Therefore, is backup power to ensure the grids stability and power quality in the grid required.

The efficiency of PV modules is most effected by change in irradiance and module temperature. Especially the increase of temperature can lead to a significant efficiency loss of production of up to -20%. Colder temperatures however could lead to a temporary increase of energy production of up to +5% (Huld & Amillo, 2015). Temperatures of around 25°C are typical within a module and a rice over this leads to a loss of efficiency of around 0.4% per 1°C (Coley, 2008). So even in winter high energy production is possible if enough sun exposure is available. *Figure 2.4.* shows the irradiation and resulting production potential of several locations in Norway as they can be compared to others in mid-Europe. So even though Norway is further North than Berlin or Paris good possibilities to produce electricity through solar are given. The further North the location is the less production is possible. The biggest impact on the production will have the strong seasonal variation of sun hours during winter and summer in Norway. With summer days with sun from 16-24 hours and winter days with sun from 0-6 hours.

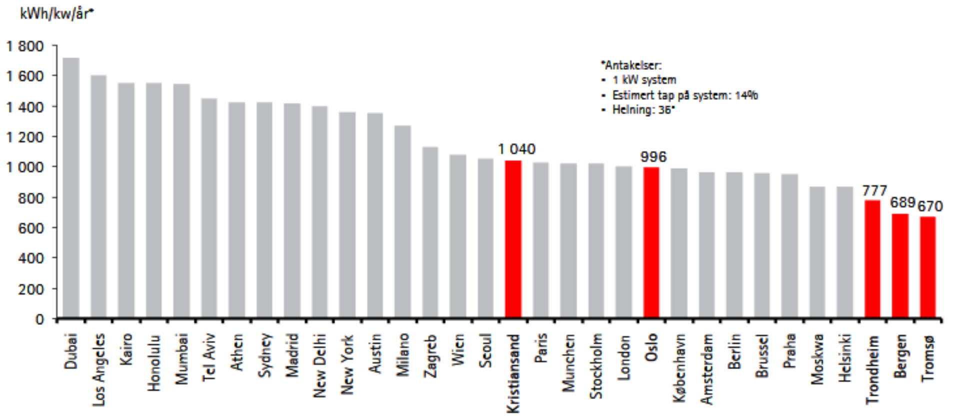
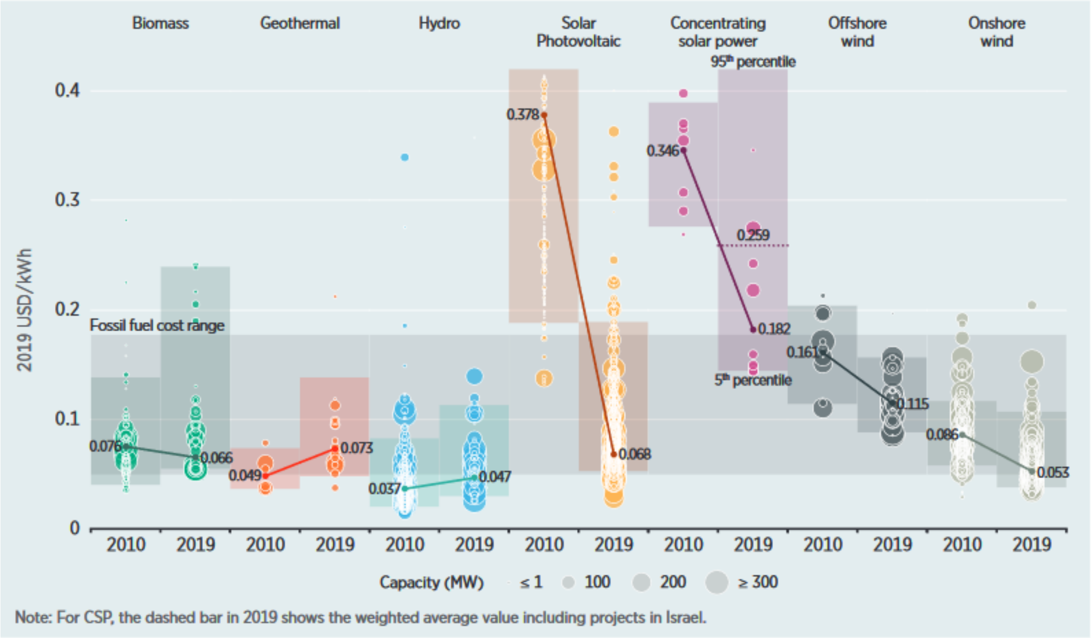


Figure 2.4. Solar PV electricity production potential across the world (NVE, 2019a).

One more challenge is the costs and investments that come with new PV systems. Even though the prices and the levelized cost of electricity (LCOE) of PV projects has decreased strongly in the last years. PV installations have not yet reached the point where they can compete in the long run with hydropower in Norway see *Figure 2. 5.*. Research shows however, that efficiency increases and further price drops of PV in the following years can be expected.



Note: For CSP, the dashed bar in 2019 shows the weighted average value including projects in Israel.

Figure 2.5. Global LCOE development 2010-2019 (IRENA, 2019b, p. 22).

Solar PV systems face political, institutional, and economic challenges and need therefore support and regulation change. The Norwegian national housing association (NBBL) see three aspects that must be changed to reach the future installation goals from NVE. Firstly, should ENOVA have a separate support scheme for housing associations and co-owners. Secondly, the government should hinder the new grid lease proposal from NVE with a fixed grid payment independent of the consumption. This will remove benefits and incentives for power savers and power producers and reduce new solar investment incentives. Lastly, remove the application obligation according to the building and planning act for block flats since detached houses are already excluded (Ask, 2020, July 15).

The actual prosumer regulation from NVE is designed to support mainly the production and consumption of electricity. The sale of electricity is restricted to a feed-in of 100 kWh and low compensation for that. The economic benefit of having a PV system lies not within selling energy, but in reducing the purchase of energy in the long run. Incentives here could make a difference in PV system investments which support grid operators. The current regulation scheme, therefore, supports the more traditional energy producers and their market standing. Further challenges arise in Norway if prosumers consider sending their electricity to neighbours to support them with excess energy. This kind system refers to the idea of peer-to peer trading of electricity in between local actors. With the goal to build a smart system where prosumers can support each other within seconds without increasing the grid load (IRENA, 2019a). This kind of technology can be a key feature in the futures energy and especially grid systems. Until further notice is this kind of system not allowed in Norway, which means that the electricity has to go through the national grid to other consumers (Hentschel, Jenssen, Thorsønn Borgen, Jarstein, & Duus, 2018). Regulation changes here could play an important role in the future of decentralised electricity generation and local system integration.

Solar PV systems are defined as renewable energy systems, especially when it comes to manufacturing of the technology difficulties can occur. The main issue is the use of raw materials and their effect on humans and ecosystems. Following this is a full waste chain and recycle scheme must established for the harmful PV waste. Otherwise the exposure of metals, crystalline silicon or cadmium will create severe problems for people and biodiversity. Through good recycling management, exposure can be avoided, loss of materials and reuse can be established through circular economy. Established factories the US, Germany or Malaysia are now able to operate at a level where they can recover 90-95% of the modules (Chowdhury et al., 2020). This already high percentage for recovering are necessary considering the peak of PV waste which is expected to happen between 2036- 2045 must be handled properly (Padoan et al., 2019). High recovery rates will support the overall ecological performance of PV systems and economic perspectives. Research highlights that China with a 32% share of world total PV installations or California as another leader however lack a recovery strategy despite the environmental importance (Chowdhury et al., 2020).

Recent research focusses more and more on PV systems which use non-toxic resources and less scare materials as the development of fourth generation cells shows. Until their commercial use is possible a clear recycle strategy of current modules will be needed to build a sustainable future relevant system.

2.4. Battery storage technology

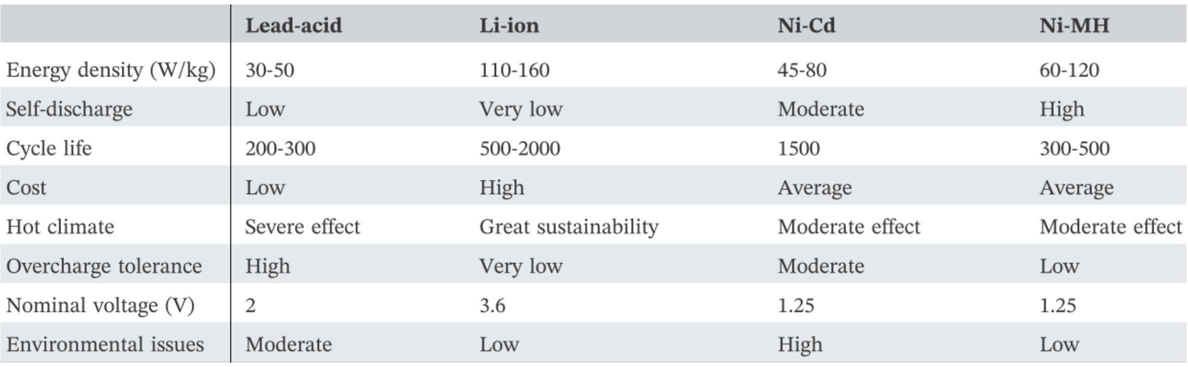
Storage of energy is vital in a system that is build up on intermittent renewable energy. Norway is known for its hydropower and reservoirs which work as huge battery and has great potential to balance high intermittency due to large scale storage and short reaction time. However, this storage capacity is locally inflexible and requires long grid connections which results in efficiency losses. Besides pumped hydroelectric storage as one of several mechanical storage technologies exists a variation of storage technologies options. Key electrical energy storage options are as well chemical, thermal, electrical and electrochemical which all entail several variations of executions and used purposes (Abdin & Khalilpour, 2019).

For local smart energy management storage is necessary that is close, not too space consuming due to local boundaries and able to coordinate between supply and demand fluctuations. Electrochemical storage has gained in this application filed in recent years big importance. Especially since produced electricity from PV Solar can be stored directly in electrochemical batteries, without the need for transformation to heat for thermal heat storage or hydrogen as chemical storage technology. Transformation processes do not occur without energy losses which can be considered as costs. Using Solar PV and store the electrons directly gives here, therefore, benefits over storage types like compressed air, hydrogen, or heat storage. A goal should be to avoid the need for transformation of energy if possible since it increases the efficiency of the system. Under the aspect of the need of seasonal or large-scale storage is the transformation necessary.

One strength of battery systems are higher round-trip efficiencies compared to pumped storage or power to-gas. Batteries can use smaller electricity price differentials du to shortest reaction time which leads to a higher utilization rate (Panos, Kober, & Wokaun, 2019). System efficiency improvements through battery storage can be crucial and limit the need of investment in extra generation capacity as compensation for storage losses and balancing needs (Panos et al., 2019). With batteries, electricity can used in times of high consumptions and low production which reduces further grid connected electricity purchase for the owner and decrease grid load. Looking into battery technology development to main battery types are connected to the storage market with Lithium-ion and Lead- acid batteries. Lead-acid batteries have been studied and improved for more than 150 years where as Lithium- ion is a more recent developed competitor (Khiareddine, Gam, & Mimouni, 2019).

Research from Khiareddine et al. (2019) shows for Lead-acid a cycle life of 800 whereas the one from Lithium-ion batteries is up to 3200. Even though exact numbers differ in research it shows the speed of development and as well that Lithium-ion in general have a longer lifespan corresponding around 12 years compared to 4-5 from Lead-acid (Khiareddine et al., 2019). So do other findings show that Lead-acid have reached cycles of 500-1800 and Lithium-ion batteries 1000-20.000 cycles (Abdin & Khalilpour, 2019).

Big characteristic differences between both technologies can be found within the energy density, cycle life, costs, hot climate influence, the overcharge tolerance, and the voltage. Especially the energy density, cycle life and costs play a role which technology is used for an application.



	Lead-acid	**Li-ion**	**Ni-Cd**	**Ni-MH**
Energy density (W/kg)	30-50	110-160	45-80	60-120
Self-discharge	Low	Very low	Moderate	High
Cycle life	200-300	500-2000	1500	300-500
Cost	Low	High	Average	Average
Hot climate	Severe effect	Great sustainability	Moderate effect	Moderate effect
Overcharge tolerance	High	Very low	Moderate	Low
Nominal voltage (V)	2	3.6	1.25	1.25
Environmental issues	Moderate	Low	High	Low

Table 2.1. Most common Batteries comparison (Farjah, Ghanbari, & Seifi, 2020, p. 2).

Nickel cadmium (Ni-Cd) and Nickel metal hydride (Ni-MH) batteries are two other technologies which are part of different energy systems as well. More Ni-Cd batteries implementation suffer from their high environmental impact and toxicity of cadmium and relatively low energy density. Ni-MH is restricted through high discharge rates and relatively low cycle life according to *Table 2. 1.*. Other research and development highlight that Ni-MH batteries reached at least 2000 cycles or even higher than Lithium-ion and a discharge rate closer to Lithium-batteries (Abdin & Khalilpour, 2019; Revankar, 2019). Nilar a US-Swedish energy storage company has focused on Ni-MH battery development and were able to demonstrate crucial achievements which allow to multiply the battery life in cooperation of the

University of Stockholm (Newswire, 2019). This gave them strong international feedback and recognition since it has huge impact on the more efficient use of resources (Johnson, 2020).

Some Life Cycle Assessments show that Ni-MH batteries perform environmentally significant worse than Lithium-ion batteries in their analysis however are much safer and not inflammable (Mahmud, Huda, Farjana, & Lang, 2019). Even though Lithium-ion batteries uses toxic lithium and more cobalt as Ni-MH, another report points out the following: “Considering the fact that NiMH batteries are one of the best cells for the environment, we can say that the use of lithium-ion batteries has the least destructive effects (Torabi & Ahmadi, 2020a). They conclude, however, later that Lithium-ion have the most significant contribution to greenhouse gas emission and metal depletion, whereas Nickel-Metal hybrids have a significant higher energy demand (Torabi & Ahmadi, 2020b).

Based on the collected information two things must be pointed out. Firstly, the development is fast, and it is not always clear which battery is currently better when it comes to environmental performance due to several uncertainties within the value chain. Due to this development neither is easy to point out which battery is better since both are commercialised used and have their place in the market. However, the next section will show that the recent development in the field of lithium-ion is a big chance.

Secondly, none of those batteries can be described as sustainable or environmentally friendly due to the high resource use. A comparison between different batteries is, however, necessary to guide and motivate improvements even though the comparison as shown is not easy. When it comes to environmentally friendly and sustainable batteries the focus must be on resources which are fare away of hazardous or toxic for environment and humans. One of those is a regional company in Stavanger which aims to create super capacity batteries and turn wooden saw dust into super-activated carbon as positive electrode and silicon from sand as anode (Beyonder, n.d.) . This would not require cobalt, nickel and other heavy metals and would be renewable and recyclable. Such a solution would take energy storage on a new level and is needed under the increasing demand for storage (Explorer, n.d.).

Despite those great prospects for the future this study must focus on solutions that are accessible as possible solutions right now. A case study shows thereby that Lithium- ion or Lead-acid batteries have significant positive impact on peak consumer load management. Furthermore, is shown that even without Solar PV production battery storage can be operated economically to support the grid (Kim, Cho, Kim, & Byeon, 2019). Different research on both technologies performance and development highlight that Lithium-ion batteries will perform techno-economically better than Lead-acid in different case studies (Dhundhara, Verma, & Williams, 2018; Khiareddine et al., 2019; Kim et al., 2019; Olaszi & Ladanyi, 2017; Zubi, Dufo-López, Carvalho, & Pasaoglu, 2018). Especially the huge development and potential that lies still within Lithium-ion batteries makes future integrations more likely. The current costs which decline 8-16% annually within Lithium-ion battery technology and costs development of batteries have been rather conservative in the past give huge opportunities (Child, Kemfert, Bogdanov, & Breyer, 2019; Khiareddine et al., 2019).

Zubi et al. (2018) however, indicates in the case of grid connected and decentral installations suffer from their high costs and according to that a too high kWh price. Therefore, an open competition with Lead-acid, NaS, Ni-MH and other technologies is to be expected. The disadvantages of low energy density or O&M requirements are no setback in bigger stationary installations(Zubi et al., 2018). The advantage of Lithium-ion batteries lies within cell technology like Lithium iron phosphate (LFP) which demonstrate high cycle life, safety, more eco-friendly and abundant material use which can become crucial in increasing installation size (Telaretti & Dusonchet, 2017; Zubi et al., 2018). Other prominent cell types Lithium cobalt oxide (LCO), Lithium manganese oxide (LMO), Lithium nickel cobalt aluminium oxide (NCA) and Lithium nickel manganese cobalt oxide (NMC) (Zubi et al., 2018). NCA and NMC batteries are especially known for their use within EVs. NCA is mainly used by Tesla with an energy density of (200–250 Wh/kg) and 1000–1500 full cycles. Whereas other car producers use NMC with an energy density of 140–200 Wh/kg and 1000–2000 full cycles.

How fast the current development in the battery development the following two examples. In July 2020 researcher from the US shared their findings of Cobalt free High-Nickel NMA battery which should perform at a similar level as the established NMC and NCA batteries (Li, Lee, & Manthiram, 2020). Current LFP battery development is making progress so that Tesla decided to start using and developing the same technology as the Chinese car producer BYD which used them exclusively until then (Forbes, 2020).[1]

2.4.1. Applications and benefits of batteries

After giving an overview about some crucial elements of battery technology development and first impressions on how they are used, focuses the next part more on the different application areas and their roles within the electricity storage system.

I want to make here a distinction between two main utilisation types of battery storage which are currently considered in the energy storage system planning. Stationary ranging from small to big scale batteries connected to local electricity production and grid or mobile batteries like from EVs or Containers.

Small scale stationary batteries also called home storage systems (HSS) are planned as part of the prosumer development and use of locally own produced electricity and have mostly a capacity range bellow 10 kWh (Figgener et al., 2020). The storage is mostly located in the same or nearby building with stable temperature and environment. The technology is already well developed and in many cases in commercial use within Norway and worldwide. The integrated battery is charged with overproduced electricity or during low prices at the grid to cover later peak demands or low internal production.

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[1] Table with extensive overview (until 2018) of battery technology used in EVs by (Zubi et al., 2018, p. 288).

Industrial storage systems (ISS) or midsize systems range from bellow 100 kW/h to several 100 kW/h capacity. Their main application is behind-the-meter (BTM) services like uninterrupted power supply, increase Solar PV electricity self-consumption or support for diverse charging stations. Larger battery installations are as well used within front-of-meter services for grid frequency reserves (Figgener et al., 2020). Prices for systems with a size up to 140 kw/h are varying between 770-2200 €/kwh where most systems were between 1000 €/kWh and 1500 €/kWh (Figgener et al., 2020; Tsiropoulos, Tarvydas, & Lebedeva, 2018). Prices are affected by size and the battery technology which is selected where Lithium-ion are more costly (Tsiropoulos et al., 2018). Larger projects do usually have a lower kWh price due scaling up and economy of scale factors. Tsiropoulos et al. (2018) points out that a huge difference exists between reported prices with a factor of 10 for example for Lithium batteries which makes detailed cost structures more uncertain. Like with reported prices for stationary storage of 220 €/kWh.

Large scale storage-systems (LSS) or battery parks aim to provide large scale electro chemical storage and direct grid support during peak demand or excess production of renewable energy (Hole & Horne, 2019). However, are these installations locally space consuming and not able to be placed everywhere due to the big battery stocks. Installations are more likely placed outside and must be resistant to climatic changes. Even though battery prices for stationary are according Zubi et al. (2018) too, high to be economically, research projects in Norway shows that it is already economically especially in the grid balancing market (Hole & Horne, 2019). Considering the current technology and costs development batteries could play a role in manging the future grid. Most promising Battery technologies dependent on application type are according to Figgener et al. (2020) Lithium-ion, Lead-acid, redox-flow and high-temperature batteries. Newer developments from Nilar, Beyonder and other companies can play a more crucial role here.

Within the section of mobile batteries especially EV batteries have become a lot of attention in recent times due to the increasing development of transport electrification. There prices have dropped in recent years strongly high production and development rates. So are prices within a range of 114 €/kWh for lithium batteries or 107 €/kWh specifically for Tesla batteries in 2019 (Forbes, 2020; Scerra, 2020).[2]

Mobile EV batteries can be an important resource for the efficiency of the grid development. Due to Norway's electrification strategy to have 500.000 EVs in 2030 which gives an equivalent electricity battery capacity of 2250-4000 MWh. Resulting of 500.000 cars multiplied with an expected average car battery capacity of 45-80 kWh (Horne, Buvik, & Hole, 2019; IEA, 2020; Statista, 2020). This could be directly use to get charged with excess electricity of RES or within the vehicle to grid (V2G) strategy. Technology would allow the transfer of electricity stores in EV batteries into the local grid during peak demand and insufficient supply to support frequency changes (Neves, Marques, & Fuinhas, 2018). Research highlights that EVs are part of potential strategies for peak demand shaving besides Demand Side Management (DSM) and Energy Storage Systems (EES) integration (Neves et al., 2018). This smart integration of EVs can avoid uncontrolled charging which leads to more peak demand. Furthermore, it has the potential to avoid economic inefficiencies in the electricity system and make advantage of RES generation (Beunen, Van Assche, & Duineveld, 2015). EVs and the V2G technology have to make the increasing Norwegian EV car park a vital source which could contribute within Grids stability enrichment, energy system efficiency enhancement, voltage-frequency regulation services, virtual inertia support, reduction of fossil fuels (Dhundhara et al., 2018). Furthermore, it is stated that development of this technologies will decrease the costs of having an EV, reduces the need for backup power capacity and increases social welfare development (Greaker, Hagem, & Proost, 2019).

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[2] (1$=0,84 €)

Current research shows that this kind of technology is already in testing at different pilot projects in the Netherlands, Denmark, Great Britain ,Sweden and Germany (Casey, 2020; Horne et al., 2019). Main issues are regulatory due to pricing systems of V2G supplied electricity, battery warranty due to increased numbers of charge and de-charge cycles, software, and smart charging infrastructure. The smart charging infrastructure must be developed in Norway relatively fast otherwise will the high numbers of EVs lead to huge peak demand and risk the grid stability (Greaker et al., 2019; Neves et al., 2018).

Large scale mobile battery containers are solutions that can bring to certain areas a high amount electricity without big infrastructure development for example on construction or event sites in remote areas to replace polluting diesel generators. Furthermore, those are easily transportable and to some degree protected from weather and climatic changes. Their application range is wide from peak load capping, charging infrastructure, emergency supply or storage of energy overproduction. The following study tested for example three different containers for German wind power integration with a container storage capacity of 1-1.5 MWh, 6000- 7000 cycles and total capital costs of around 624.030- 1.164.460 € (Siddique & Thakur, 2020).[3]

As shown brings the current battery development and increasing application options a lot of possibilities for renewable systems. The more widespread use of chemical energy storage technology has as well side effects that have to be expressed to make the use as sustainable as possible. As already mentioned, the use of resources within batteries that can have during production and leakage severe toxic impact on environment and humans which is addressed in the next section.

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[3] (1 $= 0,84€)

2.4.2. Drawbacks & side effects from batteries

The currently fast production and increasing demand of batteries has several issues, side effects and drawbacks and is addressed in the following section.

First is the usage of critical and rare materials which are needed for the production. Main concerns are about the resources Cobalt and Lithium. Cobalt is the major concern within the battery and especially Lithium-ion battery sector. Reserves are estimated at 25 Million tonnes. Further 120 million tonnes are estimated to exist in the ground of the Atlantic, Indian and Pacific Ocean (Zubi et al., 2018). Main production is currently in Congo and Morocco which major concerns on child labour and environmental toxic impact. Lithium-ion batteries consumed 2016 around 30% of the cobalt supply which will further increase. Global cobalt production was in 2019 140.000 tonnes which is an increase of 12,2% in comparison to the production of 123.000 tonnes in 2016 (Shedd, 2020; Zubi et al., 2018). Prices in 2019 varied from 25.645 $/t at the lower end to top prices of 92.500 $/t (Barchart, 2020). The same data points out a huge price peak in 2018 with variations between 34.750-95,250 $/t. Zubi et al. (2018) points out that the certain Lithium-ion batteries like LCO, NCA or NMC are so dependent on cobalt that prices of already 23.000 $/t would have significant impact on battery and EV prices. They could respectively increase 21% for LCO, and 3-6% for NCA and NMC with significant effect on companies and consumers.

The main action to prevent a development that hinders renewable energy development, child labour and more environmental issues lies within a better recycling and recovery scheme. Recovering cobalt from old batteries can reduce the need of virgin material up to 50% which has a significant impact (Zubi et al., 2018). Recent research shared results that recovery of more than 90% is possible and making batteries and their use more sustainable (Rice-University, 2019; Wang, Yen, Lin, & Xu, 2019). The second action is as described above the Research and Development (R&D) of cobalt free Lithium-ion batteries like LFP or the new High Nickel NAM batteries. Lithium is as well listed as critical material with global resources of 47 million tonnes and 17 million tonnes which are ranked as extractable (Jaskula, 2020; Zubi et al., 2018). Global lithium consumption and production ramped up in recent years and was in 2019 258.000t and a global production of 486,000t (Jaskula, 2020). In 2030 around 400.000t could be needed just for batteries due to transport electrification (Zubi et al., 2018). In the short- and medium-term development is not critical due to the still huge enough reserves. Considering the environmental consequences and a long-term perspective, the dependence on virgin material should be reduced to a minimum. Depending on the lifetime of the produced commodities a huge amount of batteries that need to be recycled arises. Current recovery rates of 50% highlight the potential that contribute with up to 40% to the new battery production (Gupta, 2019). Through recycling innovation the Finish energy company Fortum achievements to recycle 80% of lithium of EV batteries and German car producers aim to reach at least 96% (BMWi, 2015; Gupta, 2019). These numbers show the huge potential, however, as well as numbers from Japan show that the collection rate of batteries is at low 10% or that around 95% of batteries end up as landfill mass in the US (Zubi et al., 2018). Better numbers are revealed from the EU where in 2018 at least 44% of batteries were collected for recycling in relation to Placed On the Market (POM) sales volume (Eurostat, 2018). Stricter guidelines and regulations in relation to recycling and removal of batteries will be needed otherwise Lithium have to be classified as a near critical resource in the long-term.

Besides Cobalt and Lithium are nickel and graphite important materials for the battery production. However, are concerns about both not necessary in the current situation as the following paragraph will show. Identified land based nickel resources are estimated to be 130 million tonnes and extensive nickel resources were found in the manganese crust and ocean floor (McRae, 2020). Reserves are estimated at 89 million tonnes and annual production in 2018 of 2.4 million tonnes. Furthermore, the recycling and recovery of nickel is gaining more importance so cover current recycling around 47% of nickel consumption (McRae, 2020; Zubi et al., 2018). Battery production has a low share of 4-5% of global nickel demand even though several battery types use nickel. Global Graphite resources are estimated to be over 800 million tonnes, global reserves at 300 million and the annual production in 2018 of 1.12 million tonnes (Olson, 2020). Concerns could be expressed about the 60-70% supply share of China but not about the amount of resources or reserves. Due to the abundance of graphite plays, recycling and recovery is not a major role currently. However, more attention is gained in the refractory of products and within more environmental battery research (H. Wang et al., 2019). Due to the mentioned aspects should neither nickel or graphite a critical resource for battery production and have negative effects on energy storage development.

Environmental impact and performance are one of the major debates in our society when it comes to the huge increase use and production of batteries. Therefore, it is important to take a closer look into the lifecycle emission of batteries. Roman et al. came in his literature review and research to a conclusion that currently the greenhouse gas burden of batteries is between 150-200 kg CO_2-eq/kWh (Romare & Dahllöf, 2017). Furthermore, they come to the conclusion that the “largest part of the emissions, around 50%, is currently from battery (including cell) manufacturing” (Romare & Dahllöf, 2017, p. 42) and resulting in big part from fossil fuel energy used in the production process. Results from (Ellingsen, Hung, & Strømman) vary even stronger from 38–356 kg CO_2-eq/kW h due to assumption and variations of cell components and design. Great potential shows production which used recycled material lowered lifecycle emissions down to 3.6–27 kg CO_2-eq/kWh (Ellingsen et al., 2017).

The sustainable effect of batteries can be showed well by comparing EVs and fossil fuel cars. Even with a carbon intensity of 0.56 kgCO_2/kWh in the German electricity grid a EV will have a much lower CO_2 emissions of 9 kg CO_2/kWh compared to gasoline with 19 kg CO_2/kWh. EVs in Norway with electricity carbon intensity of 0.05 kg CO_2/kWh has a carbon footprint around seven times smaller than a gasoline car(Zubi et al., 2018).

The combination of clean renewables energy supply allows the batteries to contribute on a global scale to sustainability. However, batteries cannot be described as absolutely environmentally friendly since many uncertainties in lifecycle analysis of batteries are present as the research shows. The contribution to a more sustainable and stable grid development with stationary battery storage systems is given so to ensure that environmental benefits of the technology attention must be paid on the whole value chain until recycling.

Especially recycling and recovering could offer major contribution caused by the big amounts of battery waste generated by EV and stationary batteries in the near future. Research and practical implications show promising results which must be optimized and commercialised as described previously.

This will cut the already falling costs that are described as too high and is a major barrier to further installations and development. The issue of batteries fading and losing capacity is currently under strong review since it is one of the main issues with installations that are planned as long-time installations. However, lifetime of batteries and their degradation time is an issue which has to be worked on, especially batteries with intensive usage. The case at Kim et al. shows, however, that even though the fading patterns were higher than expected an economic beneficial operation was possible (Kim et al., 2019).

3. Theoretical frameworks

This master thesis uses theoretical frameworks that have their origin in transition studies which are used to explain and analyse a certain type of social change that is needed to overcome the big questions like climate change and sustainable development. A transition can be understood as “specific type of social change, which is characterised by non-linearity, a long time frame […] and structural transformation” (Van den Bosch, 2010, p. 37).

The complexity within transition theory and transition studies can be described best by looking at *Figure 3. 1.*. For this thesis it is essential to understand the connection between the multi-level perspective (MLP), Transition Management (TM) and Strategic Niche Management (SNM). This will conclude in underlining the need of Transition experiments towards solving societal big questions.

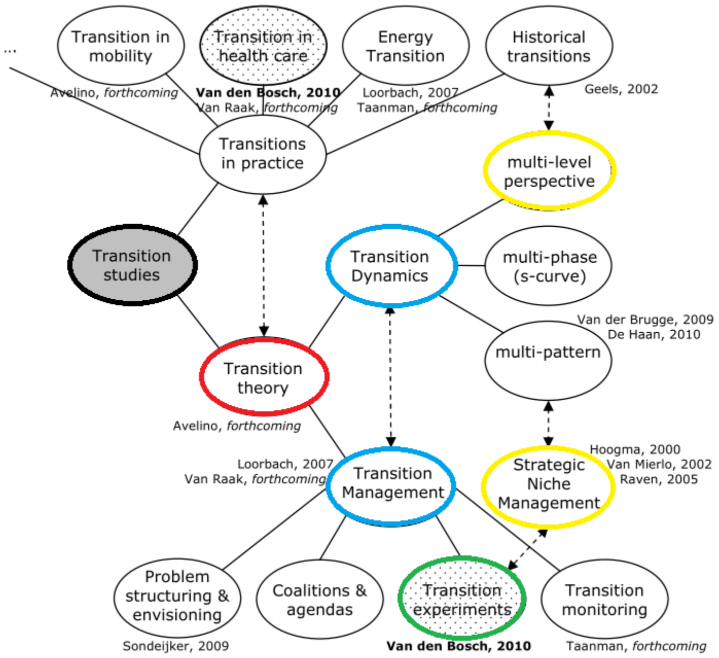


Figure 3.1. Transition studies in the recent research field (Van den Bosch, 2010, p. 37).

The MLP provides understanding of how social-technical transitions can be realized, in which time frame and especially what level of actors are involved. Therefore, it is vital to understand the single connection within the MLP before going further to Transition Management or experiments. Especially the perception that policy plays a crucial role in that change is of immense importance here. Building upon that, the governance approach of Transition Management has the idea to guide and influence transitions towards a sustainable direction. Experiments are the main instruments of Transition management to support transitions. Through the idea of Experiments a close connection between TM and Strategic Niche management can be outlined. SNM aims to stimulate learning processes and processes of societal embedding of socio-technical innovations (Van den Bosch, 2010). However, does SNM specific learning and experiments happen in controlled and protected niche areas and misses the bigger social system transition, which this thesis is looking into.

3.1.Multi-Level Perspective

As in *Figure 3.1.* to see has the MLP it roots within the field of Transition Dynamics with the aim to develop understanding on how the dynamics of transition and processes come. Transition Dynamics investigates past, ongoing, and future transitions. From this outgoing has the MLP developed a good middle-range framework for analysing historical socio-technical transitions towards sustainability (Geels, 2011).

> “The basic ontology behind the multi-level perspective stems from the sociology of technology, where three interrelated dimensions are important: (a) socio-technical systems, the tangible elements needed to fulfil societal functions; (b) social groups who maintain and refine the elements of socio-technical systems, and (c) rules (understood as regimes) that guide and orient activities of social groups” (Geels & Kemp, 2007, p. 442).

There are three “analytical and heuristic levels” (Geels, 2005, p. 683) of the MLP which are, ”technological niches, the socio-technical regimes, and the socio-technical landscape,” (Geels & Schot, 2010, p. 18) and it is within the interdependency of these levels in which the framework for transition is built (Geels & Schot, 2010). The stability which is within each multifarious individual level in the MLP is dependent upon the symbiotic positioning which exists between the constituents actor (Geels, 2011). and it is this stability or lack thereof which creates either “lock-ins “ or “windows of opportunities” (Geels & Schot, 2010, pp. 20-21). Transitions stem from the “alignment of trajectories within levels, as well as between levels” (Geels & Schot, 2010, p. 18). It is the synchronous synergy of the three independent levels of the MLP which utilizes the strengths and weaknesses of the actors and networks to form an incremental transition, using instability, inability, acceptance, and opportunity to create and complete the transition (Geels & Kemp, 2007).

The socio-technological landscape is a vast extrinsic layer of the MLP that exists as the present grim which feeds the societal storyline which is universally shared and lived through (Geels & Schot, 2010). The socio-technological landscape "highlights not only the technical and material backdrop that sustains society, but also includes demographical trends, political ideologies, societal values, and macro-economic patterns" (Geels, 2011, p. 28). This remote landscape is inaccessible to the actors and their ideas in regime and niche levels and within it, there exists only a long term nearly stagnant opportunity for change (Geels & Schot, 2007). "Landscape developments comprise both slow-changing trends (e.g. demographics, ideology, spatial structures, geopolitics) and exogenous shocks (e.g. wars, economic crises, major accidents, political upheavals)" (Geels, 2018, p. 225). The decision towards the electrification of the transport sector and its strategy as cause from the Climate Crisis and pressure on industry and politics.

Niches comprise the "micro-level" (Geels & Schot, 2007, p. 400) section of the transition which consists of connections often existing on the periphery of the regime where radical innovations are born and nurtured through experiments (Geels, 2010). These innovations grow as they "build up internal momentum, through learning processes, price/performance improvements, and support from powerful groups" (Geels & Schot, 2007, p. 400).

> "Niches gain momentum if visions (and expectations) become more precise and more broadly accepted, if the alignment of various learning processes results in a stable configuration and if social networks become bigger (especially the participation of powerful actors may add legitimacy and bring more resources into niches)" (Geels, 2012, p. 472).

The socio-technical regime is an adamantine level consisting of a multiple of actors from various areas. These actors hold on to thought and action to their previously formed ideologies from the drip down in the socio-technical landscape (Geels & Kemp, 2007).

The socio-technical regime "refers to the semi-coherent set of rules that orient and coordinate the activities of the social groups that reproduce the various elements of socio-technical systems" (Geels, 2011, p. 27).

The behavioral bylaws followed by the actors in the regime “coordinate and guide actor’s perceptions and actions” (Geels, 2012, p. 473). These repetitive actions and installed bylaws slow transition down. (Geels, 2010). The established regime within the transport sector will try to postpone the electrification of transport. They want to keep the existing system running as long as possible to maximize own revenues and avoid investments. This must be overcome with the political support from the political landscape which is shown for example from the revealed strategies and economic support for Elnett21.

Geels and Kemp (2007) describe the political landscape as a possibility to create room for system change through revolutions, new coalitions, and new ideas. Because the scholars have not followed this idea further, Geels received various criticisms on that and other points, to which he responded: “Geels combines power and politics to the idea that policymaker and incumbent firm often form a core alliance at the regime level to maintain the status quo” (Geels, 2014, p. 26). As this is not the general case and especially not in democracies with opposition parties O. Langhelle et al. argument further in the paper “Where are the politics? Situating transition politics within the multi-level perspective” for a separate political landscape to see in *Figure 3.2* (Langhelle, Kern, Meadowcroft, & Rosenbloom, 2018, pp. 7-8). It is described by the authors as a more fluid landscape which has the possibility of slow leaden changes however it can also have swift changes and “consists of different processes operating in a different political, spatial and temporal scales” (Langhelle et al., 2018, p. 9). The political landscape is “exogenous and endogenous to the regimes and niches at the same time” (Langhelle et al., 2018, p. 10). Kuzemko et al. describe the location of politics compared to Geels in the MLP as “politics [...] seems to take place rather amorphously at the exogenous ‘landscape’ level” (Kuzemko, Lockwood, Mitchell, & Hoggett, 2016, p. 98).

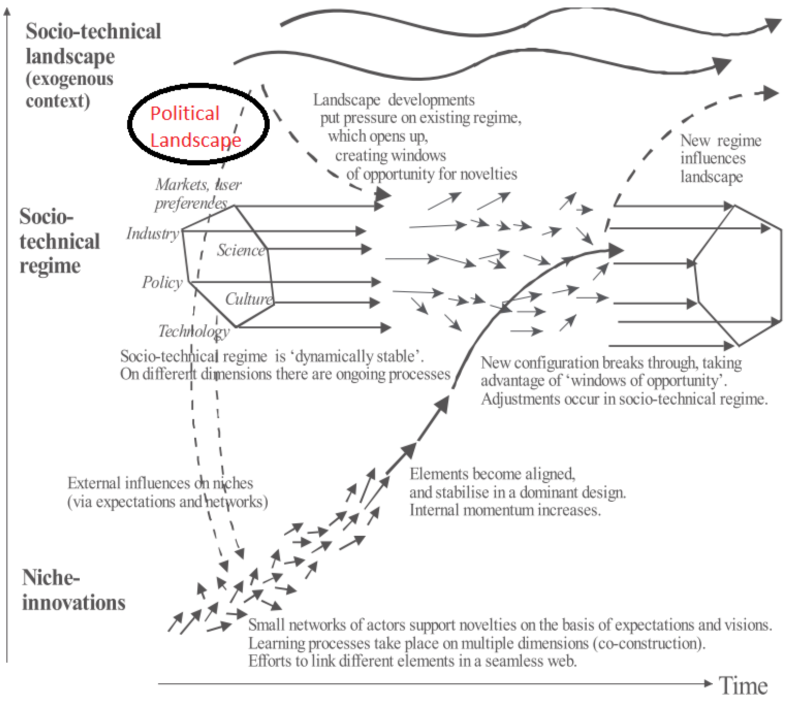


Figure 3.2. MLP actors and levels (Langhelle et al., 2018, p. 14).

Following the idea that the political landscape and politics can influence how transitions can be implemented. For the whole Elnett21 project the political landscape plays an important role. ENOVA SF is a state enterprise owned by the Norwegian Ministry of Climate and Environment which has the task to" reduced greenhouse gas emissions, development of energy and climate technology and a strengthened security of supply" (ENOVA, 2018).

ENOVA as political player supports Elnett21 with 40 million NOK from a total project scope of 110 million NOK (ENOVA, 2019). ENOVA makes with that important contribution towards the strategic development and testing of of technologies and their integration. Elnett21 can be seen as a niche project which get strategic support from political and other actors. Therefore, it is suggested to look closer into the theoretical aspect of Strategic niche management and Transition Management from demonstration projects.

3.2. Strategic Niche Management

Strategic niche management (SNM) can be related to the MLP and TM but focuses more on stimulating the development, formation of niches and experiments as a way of stimulating radical innovations. It is used in relevance as an analytical tool to study the development of niches and as a governance tool (Torrens, 2018). Niches are platforms for interaction which emerge out of interaction between many actors. They cannot be controlled, and the role of policy has to be understood as modulating and enhancement (Kemp, Schot, & Hoogma, 1998, p. 186). Policy takes over the central actor role to initiate experiments, improve learning, shape economic success of innovative technologies. However, niches can be restricted in their development due to new legislation and regulations or other actors. Despite this restriction it lies in the nature of the niche to find ways and methods around these restrictions and is therefore not controlled and navigates through the obstacles. SMN has been used strongly in relation to ex-post analysis of technical innovation and what from this development can be learned about the use of SNM (Van den Bosch, 2010). SNM lacks an approach that breaks out of the niche and ex- post analysis (therefore we will look further into TM) to be more useful in experimental analysis.

3.3. Transition Management

Transmission management was developed as a governance approach with the aim to create transition areas, where front- runners can realize and experiment with new pathways towards sustainability (van den Bosch & Rotmans, 2008). Management means in this context there is no top down control and steering, rather it must be understood as adjusting, adapting and influencing the development (Rotmans & Kemp, 2008). This approach will be used to transform persistent problems into a visionary challenge and explore possible options and pathways by applying experiments (Rotmans & Kemp, 2008). In contrast to SNM , TM does have a social problem as starting point whereas in SNM the starting point can often be referred to a technological innovation which needs an experiment and testing area.

TM has its roots from complex systems science and research on new forms of governance to work out practical guidelines from case studies and a more practical management framework approach (Loorbach, 2007; Van den Bosch, 2010). This management framework contains different instruments from complex system analysis, experiments to monitoring and evaluation. The TM cycle *(Figure 3.3.)* collects and connects the instruments into four activity clusters. For this thesis especially the third cluster is relevant when it comes to executing projects and experiments on an operational level. Step one of the cycles is developing the strategic long-term sustainability vision and problem structuring which is one of the main points of TM. The second step can be overall described as a tactical level within the process (Kemp, Loorbach, & Rotmans, 2007).

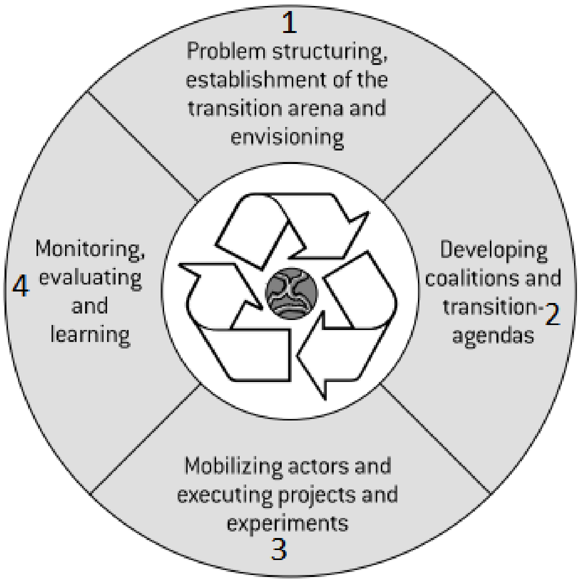


Figure 3.3. Transition Management cycle (Van den Bosch, 2010, p. 45).

Transition Management as a specific form of multi-level governance has three factors which are relevant if an innovation should occur through participation and interaction. First a selective participation based on their specific roles, competencies, background, and ambitions for innovation. Second by focusing on a long- term collective sustainable development process with mutual adoption. Thirdly the aim to initiate a transition of social system by promoting destabilization and changes in structures, cultures and practices (Loorbach, 2007).

A more practical approach towards innovation within these two governance approaches are their ideal typical equivalents as experiments, which gives a more structural understanding of the idea of Elnett21.

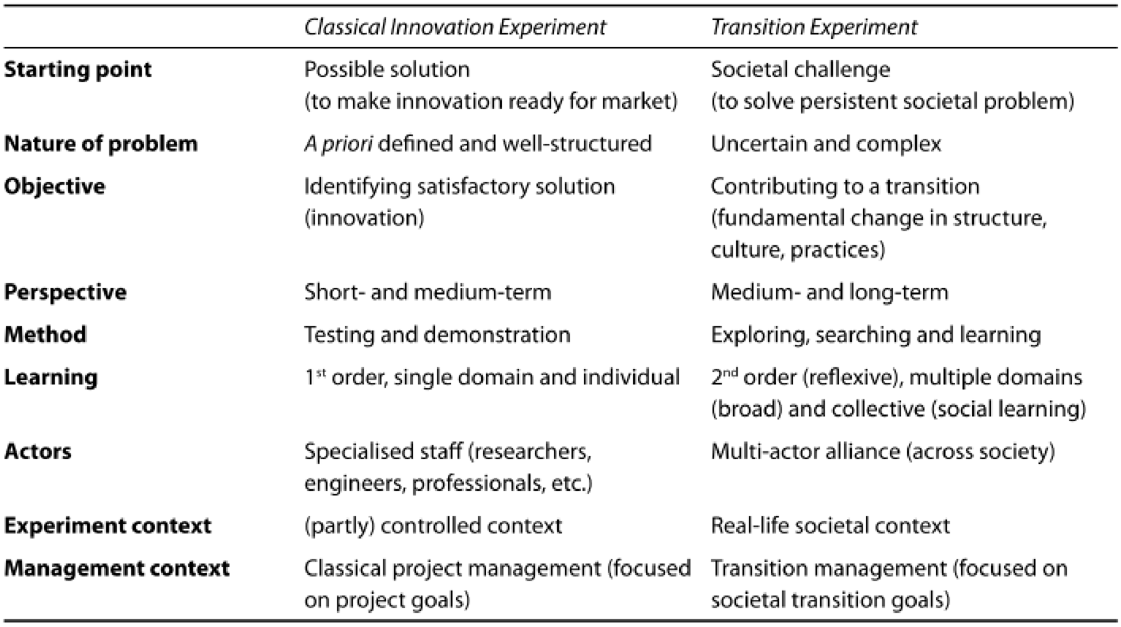
3.4. Transition Experiments

Transition Experiments have their roots within evolutionary theory and complex system theory presenting the relevance of variation, selection and the effect that small changes can have impactful consequences (van den Bosch & Rotmans, 2008). Innovation Experiments, however, has its foundation within innovation theory and the concept of SNM to develop innovations within niches and isolated from the mainstream (Geels & Schot, 2007; Levinthal, 1998).

Transition experiments were first defined by Rootmans as “practical experiments with a high level of risk (in terms of failure) that can make a potentially large contribution to a transition process” (Rotmans, 2005, p. 50). A newer transition experiment definition with higher theoretical support and related to the Brundlandt definition of sustainability is defined as “innovation projects that explore radically new ways of meeting societal needs and solving persistent societal problems” (Johansen & van den Bosch, 2017, p. 61). Since transition experiments are driven by social needs, innovation that occurs is not just socio-technical but inherently institutional, legal, financial or socii- cultural (van den Bosch & Rotmans, 2008).

Classical Innovation Experiments are different since experiments have there a socio-technical nature in which the starting point is often a technological innovation. SNM focus mainly on setting up experiments by testing and demonstration in a short-term medium term. The transition experiments explore more and search for a god solution with a broader governance approach including strategic, tactical, and operational transition activities (Van den Bosch, 2010).

For a better understanding and classification of the differences between innovation experiments and transition experiments lists *Table 3.1.* them in a short manner. The two extreme ideal types of experiments in *Table 3.1.* are radical ideals and more likely is it to find hybrid forms. However, a distinction is important as it shows with different starting points, of the experiments.



	Classical Innovation Experiment	*Transition Experiment*
Starting point	Possible solution (to make innovation ready for market)	Societal challenge (to solve persistent societal problem)
Nature of problem	*A priori* defined and well-structured	Uncertain and complex
Objective	Identifying satisfactory solution (innovation)	Contributing to a transition (fundamental change in structure, culture, practices)
Perspective	Short- and medium-term	Medium- and long-term
Method	Testing and demonstration	Exploring, searching and learning
Learning	1st order, single domain and individual	2nd order (reflexive), multiple domains (broad) and collective (social learning)
Actors	Specialised staff (researchers, engineers, professionals, etc.)	Multi-actor alliance (across society)
Experiment context	(partly) controlled context	Real-life societal context
Management context	Classical project management (focused on project goals)	Transition management (focused on societal transition goals)

Table 3.1. Two characteristics of experiments4 (van den Bosch & Rotmans, 2008, p. 23).

Three main concepts are important by talking about transition experiments. First as previously named, the main point of TM the societal challenge which provides the level of direction, scope and region (Van den Bosch, 2010). The challenge guides the search and learning process of the experiment. Second concept is innovation which relates to everything that can be understood

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[4] A “classical innovation experiment” refers to the dominant instruments to stimulate
innovation, such as pilot projects and demonstration projects that are supported by subsidies or private R&D investments.

as new. As said in the previous definition a transition experiment is a specific type of innovation project.

The main innovation idea behind transition experiments lies within system innovation (Van den Bosch, 2010). System innovation is in relation to a concrete sector or region, that a system innovation fulfils an existing or future societal need in a fundamentally different way which is in Elnett21 the way of future transport. System innovations are as well describes as "organisation-transcending innovations that drastically alter the relationship between the companies, organisations and individuals involved in the system" which shows a close relation to the different MLP (Rotmans, 2005, p. 11).

The third concept is about learning which can be in an active or interactive way (Van den Bosch, 2010). The main goal of the learning process is to support a fundamental change within culture, structures and daily practices of multiple actors involved as to find as well in part of the MLP. Therefore, it is necessary that the experiment is realized in a real-life social context and reach highest and precise level of learning, which especially the goal from Elnett21(Van den Bosch, 2010). An ideal type of transition experiment would require a Transition Management context that supports transition experiments with other TM instruments like a complex systems analysis, long-term sustainability vision, transition arena and transition pathways (Van den Bosch, 2010).

Especially TM and the experiments are important to get a better understanding about the Elnett21 and Stavangerregionen Havn case within the academic research. It shows the bigger picture of system innovation and change, from that Elnett21 in general is just a small step towards a more sustainable and electric transport system. Transitions are thereby not always a question of technical and practical execution. Moreover, is it important that support and cooperation from different actors is given to reach the state to implement a transition and development experiment otherwise the developed technology could stay within the niche as shown through the MLP.

4. Research Methodology

4.1. Research Design

The research design is the roadmap for a successful implementation of research. Therefore, the following paragraph will show why a mixed method approach was selected. The concept of using mixed methods has gained more acceptance and prominence in the last years especially in interdisciplinary research. Even though there are several critics about the combination of qualitative and quantitative research newer views see mixed methods as feasible and desirable (Bryman, 2016).

To ensure the quality, reliability and validity of the mixed method approach we will use six guidelines that describes Good Reporting of A Mixed Methods Study (GRAMMS) developed by (O'cathain, Murphy, & Nicholl, 2008). Those were developed due to lack of transparency in the reporting of mixed methods studies within health service research but as well in other sectors.

The research of the study focuses on a mixed method approach analysing current development within the market and research and creating and collecting data around estimation of PV solar and electricity consumption. With an extensive content analysis on decentralization, why and how Solar PV and battery storage are future oriented technologies. A theoretical setting why demonstration projects like Elnett21 are crucial for reaching climate and sustainability targets through experiments and actor support within the society. The extensive review showed that solar and battery storage should have a bigger role in the future energy and electricity system in Norway. The review was heavily based on a qualitative literature review and analysis. To support these results the quantitative part of this research will focus on solar and battery potential in the case of Stavangerregionen Havn and the demonstration project Elnett21. This will either support the idea and gives some chance for generalization of the findings or falsify it in that case study. This design helps to combine data and findings in a social science study and the use of techno- economic analysis methods.

The research design can be described as an exploratory sequential design with its origins in qualitative data collection and content analysis. This builds the foundation and preparation for the prioritized quantitative data collection and analysis. The findings will then show if the qualitative results can be verified by the quantitative results (Bryman, 2016).

The priority within the data collection lies within quantitative data to explain the case of Risavika and Stavangerregionen Havn and its techno-economic analysis within the bigger picture of the need for electrification and large-scale demonstration projects. Due to the sequential method, is the qualitative data collection and analysis the first step. Outgoing from those results and understanding the quantitative collection and analysis can be developed and placed in the correct setting.

The qualitative data collection occurs within written long and short-term case studies, research reports and development news and trends of the research and market field. Through that the study has the possibility to use newest published information to build the foundation. The pace of technological development is high and happens on a global scale, so the constant flow of information ensures the quality of the research. One example is the shift in the use of PV cells from 270-300W to newer and now more cost effective 320-340W panels. Qualitative Interviews are not able to ensure the constant flow of information and are difficult to conduct on a global base.

The quantitative method collects electricity consumption and cost data related to the ferry-terminal at Risavika. Software's from K2 and PVsyst are used to generate data which will be used to show the production potential, simulated production, shading, and economic performance. The integration of the qualitative method in the first sequence guides the direction in which the quantitative analysis and results should go. The numeric results and their fineness can, however, just be provided from quantitative methods.

There is some limitation when it comes to qualitative content analysis. Many reports and articles are based on quantitative results and research, which increases the share of quantitative data. However, this is necessary to get an understanding of the technologies development and how they are used and currently applied. Additionally, the recent technology and market development within decentralisation, Solar technology and especially battery technology is so fast that the only way to keep up with this pace is article and research reviews.

The mixed method gave for this study insightful information about the status on decentralisation, the use of Solar PV and especially about the fast development of battery storage technology. Especially the information about the price and environmental performance of both technologies is crucial to generate long-time benefits with a system installation. The qualitative information about limitations and struggles of PV solar that the estimation of outcome and reliability must be compensated by storage technology to provide a reliable system. That information is then used and needed to set up the technical and economic parameters and boundaries in which the experimental case study can be simulated and analysed.

4.2. Study sides

The study location is placed in the area surrounding Stavanger in Norway. *Figure 4.1.* shows the three locations which are the central point of Elnett21 demonstration project. Element of analysis in this study will be the harbour (BÅT) in the north-west at Risavika. The Figure shows clearly the three industry and energy hubs in the region in the south the airport (FlY) and in the East Forus (BUSS).

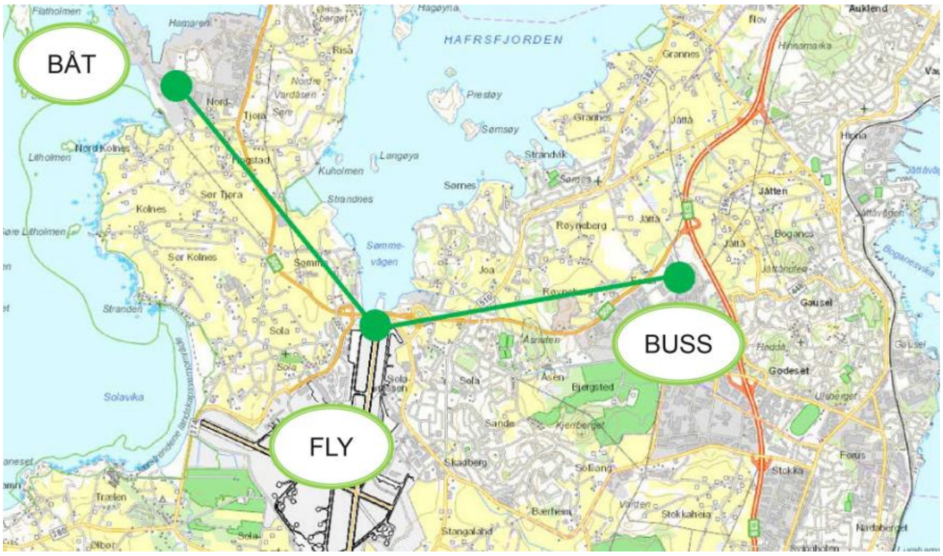

Figure 4.1. Elnett21 location layout Harbour, Airport and Forus (Avinor, 2019, p. 10).

As previously described is this area in Norway in general suited for the installation of Solar PV comparable with several regions in mid- Europe. Which results in an annual irradiation factor of 854 kwh/m2 according to the findings in the PVsyst report from the terminal building in *Table 5. 3.*. The location at Risavika is close to the open sea on the west so Solar PV roof installations must be adjusted to that and must be strong wind approved. The location due to its orientation in the northern hemisphere affected by shorter winter days and longer summer days. The study entails in total 10 buildings that should be evaluated on their solar production potential. *Table 4.1.* gives an overview over the building number, the tenant who operates the building and the address.

Bulding Nr:	Tannent	adress
1	Stavangerregionen Haven	Kontinentalvegen 31, 4056 Tananger
2	ResQ Stavanger/ Axiom Process Norge	Kontinentalvegen 35, 4056 Tananger
3	Pentagon Freight Services AS	Risavika Havnering 321, 4056 Tananger
4	Vallourec Norge	Havnering 309, 4056 Tananger,
5	Franzefoss gjenvinning	Havnering 227, 4056 Tananger
6	Franzefoss gjenvinning	Havnering 227, 4056 Tananger
7	Kuehne + Nagel AS	Havnering 247, 4056 Tananger
8	Kuehne + Nagel AS	Havnering 247, 4056 Tananger
9	Stavanger tourist Information	Strandkaien 61, 4005 Stavanger
10	Possibilty terminal Stavanger	Nedre Strandgate 89, 4005 Stavange

Table 4.1. Study cases(self-created).

The side at Risavika entails 8 roofs owned by Stavangerregionen Havn, where building 1 is the ferry-terminal building and main study point for the techno-economic analysis. Building 7&8 are the only buildings in this study what a gable roof with a North-South and East-West direction as possible to see in *Figure 4. 2.*.

Figure 4.2. Risavika study side buildings 1-8 (Finn.kart.no).

Two roof sights for the Solar PV estimation are in the centre of Stavanger at the harbour to see on *Figure 4. 3.*. Outgoing from that, 10 roofs in total should get a Solar PV modelling estimation. Building 9 is the tourist information centre and number 10 the possibility terminal (mulighetsterminalen). Both Figure *4.2.* & *Figure 4.3.* are recorded with the card function of Finn.no because building number 3 is not built yet in the actual google maps version.

Figure 4.3. Stavanger city harbour study side building 9-10 (Finn.kart.no).

4.3. Data Collection Methods and Instruments

The data sources and collection can be divided into two categories for this study. First is data that is provided from Stavangerregionen Havn like energy consumption, electricity bills corresponding to that consumption or architecture drawings from some buildings. The second category of data is generated through modeling the Solar PV roofs and production simulation.

Consumption data is necessary to see at first to which degree it could be possible to cover the demand with locally generated energy. Second to localize at which time stamps consumption peaks occur and if it follows regular patterns which later could be covered by battery storage if production is too low.

Electricity bills are later useful to identify on which scale the local electricity production reduces those bills and the long-term economic benefit of that development investment. Architectural data will be useful for construction of the 3D model needed for the production and shading simulation.

The roof modeling a web-based tool from the company K2 Systems is used (K2, 2020). With the web-tool it is possible to modulate the roofs and the corresponding mounting system for solar technology. The Web-tool is divided into six steps. First the project description with finding the location. Second the roof modulation with variables like building height, roof pitch and characteristics of the roof like the sheeting material and their corresponding friction coefficient. The friction coefficient is important to ensure later in the process a proper ballast calculation of the installation. Third step is the design of the modules and the module arrays with selecting the wanted PV modules and correct mounting system. Furthermore, are done adjustments about thermal gaps between modules to avoid overheating. Those are adjusted by load exceedance. The fourth part is related to the load estimation which requires input data like wind speed or snow load. Both are needed to ensure that the modules stay in place even in strong winds up to 28 m/s or the roof does not collapse due to snow load.

The fifth part present the ballast plan as results from the design and load calculation. If the ballast at certain roof areas exceeds the allowed maximum adjustments of the allocation of module areas and thermal gaps must be made within the previous design section. The last part of the web-tool is the summary which presents the amount of mounting equipment needed, ballast plan, mounting description from every module area and how many PV modules have been used and which energy output could be possible with that. The K2 System modeling is done to build the corresponding shading simulation system within PVsyst furthermore to get detailed information about the mounting equipment, load and orientation of the module areas.

The PVsyst software was developed to study and simulate PV systems already in 1992. The software entails tools like the construction of 3D buildings and a shading simulation. With its interconnection of historic weather data it is possible to simulate hourly production data from a model (PVsyst, n.d). For this study was used historic weather data from Meteonorm 7.1 (1991-2010) which is integrated into PVsyst. PVsyst has a wide range of functions and is one of the most powerful programmes which uses a multi-level approach and therefore used various groups like architects, PV specialist engineers or scientists. PVsyst contain three main application levels which are preliminary design and system sizing, project design and measured data analysis and tools (photovoltaic-software.com, n.d.).

The System Design board has databases on PV modules and inverters that could be used for the design or own equipment could be uploaded as well. For this study will be used PV modules from international established and well-known producers. Main panel will be from the top PV supplier Solar Fabrik according the certificates from the EuPD Research Sustainable Management GmbH (EuPD, 2020). The Mono S2 Halfcut 340-watt panel which is known as high performance module with a great cost -efficiency ratio. The conversion efficiency is listed at 20,14% and the operating temperature is given from -40°C to 85°C at the data-sheet (Solar Fabrik , 2020) . The second module which is used in a comparative perspective is from Sun Power the Maxeon3 400-watt commercial module (Sun Power , 2019). Important is to mention that this module is internationally listed with a record breaking efficiency energy conversion rate of 22,6 % (Review.Solar, 2019). Inverters for the simulation are used from the international operating company Ginlong Solis from China. The company has since been top ranked for several years internationally and delivers very good and reliable products (Review.Solar, 2020). For this master thesis PVsyst is used to create 3D models of all buildings, roofs, and PV installation. This delivers access to a simulation report for each roof with information about the performance of the installation its losses and monthly production output. It is especially important to receive the information about the realistic production data based on historic weather data including all loses due to temperature changes, irradiance level or technical factors. Based on these numbers further analysis can be done.

4.4. Data Analysis

The gathered quantitative is analysed with the following five steps.

Step 1:

The first step is the analysis of the information collected from the K2 modulation and PVsyst simulation. Those determine how many modules will be installed, what peak production is possible under 100% system efficiency and the amount of simulated production for a given year. All three findings are essential to run the project cost, cost saving potential and long-term economic evaluation.

Step 2:

The second step analyses the electricity consumption data to become an overview of the load curves and peak demand from the terminal building. The collected consumption data from the terminal building get reformatted to average monthly consumption data for every hour. This format is used that consumption and production data can be merged through a simple mathematical subtraction process. The new set entails information about the hours for every month where production is below or above consumption. The gathered results from this analysis are used to show average excess production and still existing peaks in the consumption profile. Based on this information is the sizing analysis for the battery storage executed to determine an appropriate battery size according the 2019 consumption profile.

Step 3:

The gathered invoice data for 2019 is analysed to find the main cost factors throughout the year and how much the peak demand affects the costs as a variable that could be actively adjusted through the installation of solar PV and battery storage. Further entails the analysis the merging of the simulated production data and outcomes from the electricity invoice analysis. This combination should show how much money would have been saved within the year 2019 simulation through the monthly energy production. This gives information about the savings if a 100% self-consumption is possible and savings of a more realistic self-consumption. Further will be selling opportunities for the excess energy evaluated and its possible capital earnings. Last part in the savings analysis concerns the battery storage and its possible yearly cost reductions according the Terminal invoice data of 2019.

Step 4:

The fourth step contains the analysis of Solar PV project costs in connection to prices of "NOK per installed Wp", including Operation & Maintenance costs (OMC). This should as well give an understanding of effect of OMC on projects economic performance. The project costs are based on the research of overall system prices in Norway from Multiconsult & Asplan viak report and experience of prices drops in recent years and the given module costs.

Step 5:

The last step of the analysis combines the analysis of total possible project investment costs and possible corresponding savings in the terminal building and its payback time. The analysis will cover scenarios as well with a 20% lower investment cost and a cheaper second battery storage unit which gives us different payback time scenarios. Despite the self-consumption rate are all other variables and prices hold constant to increase the compatibility between the results.

4.5. Assumptions of the Study

This study assumes that Stavangerregionen Havn has great potential for Solar PV installation and production of electricity. Furthermore, it will be assumed that through the installation of battery storage within the Terminal building gives the option for significant cost and peak demand under current prices and consumption. Lastly, it is assumed that increasing prices for grid and electricity in the future will benefit an investment in Solar PV and storage. Those assumptions can be done based on the qualitative literature review on decentral energy production and development and storage technology globally and in Norway.

4.6. Limitations of the Study

This study will face three main limitations which especially are related to economic analysis of Solar PV projects and battery storage installations.

Solar PV systems are containing a large range of different cost factors. Solar modules and inverters are a relative huge share of this costs. Other costs associated with Solar PV installations are collated under the concept of Balance of System costs (BOS). Those entail project costs cover labour costs for mounting equipment for the roofs, cabling, electronics, transport costs, permission fees.[5] These costs are difficult to calculate or estimate for companies itself and especially for individuals outside those companies. Therefore, a literature and report review of projects costs development in recent years will be done. The goal is to receive information and data about the cost share of the different categories of Solar modules, inverters, and BOS costs. Those will be collected, and an average cost distribution calculated and then used for the share distribution.

A similar limitation is given within the cost projection related to battery storage. Battery prices are decreasing rapidly due to the strong increasing production amount and development progresses. Therefore, is it possible to get monthly data about further price drops and progress. Prices within battery storage technology vary strongly due to size, capacity, material used, and cycle life as previously mentioned. This study will focus on battery cost data which is reported as actively installed and tested. Due to the reported variance of stationary storage prices is suggested to use three intervals for possible costs for battery. The intervals will range from to 7000 NOK/ kWh and 12.000 NOK/ kWh.

The third limitation of this study is the impact of weather and climate changes on the performance and generation of electricity for Solar PV, Hydropower and other sources that are weather dependent. As NVE pointed out in their report will the fluctuation of storage capacity

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[5] Appendix: BOS cost breakdown example

increase due to more extrem weather from climate change (Koestler et al., 2019). Extreme weather will affect as well Solar PV so will sunny year increase the generation whereas in rainy years the generation may drop significantly. According to Yadmelat (2019) varies the production annually between -10% and +10% over the year and in summer -20% and +20% in Norway. Due to climate change could this fluctuation increase even more. This means that the simulations from PVsyst can vary dependent on the year significantly which brings several uncertainties into the data evaluation process. The evaluation of future production data over an evaluation period of 30 years can vary significantly and therefore to be understood as a trend that could occur. During high electricity generation years from hydropower will electricity prices be in general lower as in years where less generation is possible as the summers of 2018/2019 have shown. This will make then local produced electricity more or less valuable in comparison with effect on savings and payback time. Therefore, all long-term evaluations in this study must be handled with care. *Table 4.2.* gives more information about values and boundaries needed for the following analysis and evaluation process.

Evaluation boundaries	**Value**	**Source**
Electricity price 2019 average	45,9 øre/kWh	Average bills 2019
Grid & consumption fee 2019 average	19,8 øre/kWh	Average bills 2019
Electricity price forecast 20-25- 30- 40 years	45-55-52-45 øre/kwh	(Bøhnsdalen et al., 2018b)
Grid & consumption fee 2020 average Effect consumption price	20,3 øre/kWh 80Kr/kWh	(Lyse_Elnett, 2020)
Excess electricity sell price	100 øre	(Tibber Norge AS , 2020)
Weather/ Climate forecast effect	high fluctuations	(Koestler et al., 2019)
Energy Fabrik module	0,28 €/wp	After request
Sun Power module	0,7 €/wp	After request
Industrial Battery storage prices	700-1200 €/kwh	(Figgener et al., 2020; Tsiropoulos et al., 2018)
Norwar PV system prices NOK/wp	10-14 NOK/wp	(Multiconsult & Asplan Viak , 2018)
Inverter & BOS costs	average values	(Fronius, n.d.; GreenZu, 2018; Solar Choice , 2011; WWF & Accenture , 2016)
O&M costs annually	0,5 % of Project cost	(Kvalitetssjef, 2018a)

Table 4.2. Boundaries & assumptions used in the data analysis (self-created).

5. Research Findings

The research findings of this study are divided into four main parts. First findings related to the qualitative analyses of research and literature related to the potential and opportunities of decentral energy production through Solar PV and stationary battery storage in Norway and within the context of Elnett21 as a Transition experiment towards a more sustainable society and transport division.

Second the findings related to the modulation and simulation through K2 and PVsyst for all project roofs. This will focus especially on the terminal building and its potential and possible contribution to energy production and consumption.

Thirdly the findings from the electricity invoices from Stavangerregionen Havn from 2019 and the consumption data for the ferry-terminal building.

The fourth part concentrates on the economic analysis of the Solar PV systems in a comparative perspective. The main focus will be on the terminal building and its economic performance based on simulated production data and the collected consumption and associated costs data for a time series of 30 years.

5.1.Modulation and Simulation evaluation

5.1.1. K2 Modulation

The roof Nr.10 associated with the Possibility terminal (Mulighetsterminalen) located in the centre of Stavanger is based on my abilities and knowledge not suited for Solar PV installations. Due to its wave shape major changes to the roof structure would be needed. Therefore, the Possibility terminal will be excluded from further evaluations. All remaining roofs except the two related to Kühne & Nagel are flat roofs. Most of the roofs have no major issues with shading through other roofs, building structures tress or objects. Only building three associated with Pentagon Freighet Services AS has due to its specific architecture partly issues with shading see *Figure 5. 1.*. General practice for flat roofs is the use of East-West panel constructions where one panel is directed with a 10-degree angle into East and the other into West. In this case the front placed building section in East-direction is according architecture data four meter higher than the rest of the building. Due to the sun rotation from East to West will be the marked filed Nr.3 *(Figure 5.1.)* shaded significantly from sunrise until 12.00. Especially, the East oriented modules will strongly underperform. A more efficient solution is a solely West orientation with a 10-degree angle which harvest after the sun rotation until sunset with greater potential.

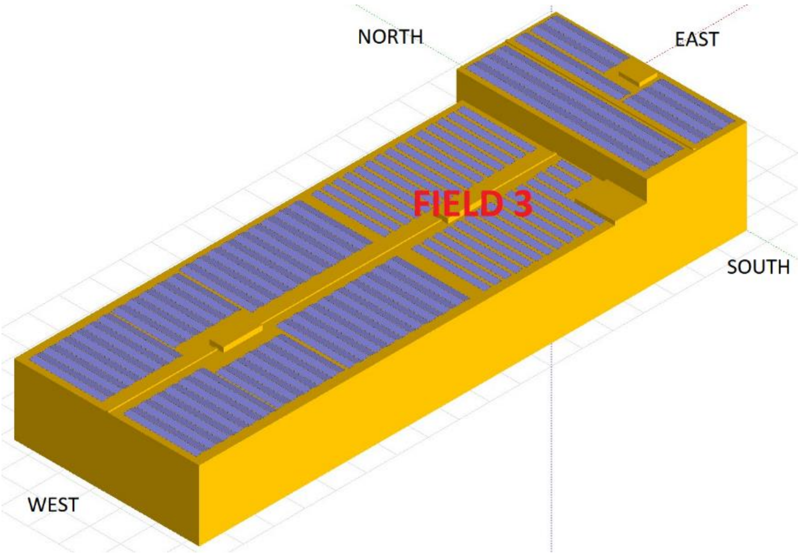


Figure 5.1. Building 3- Pentagon Freight with West directed field Nr.3 (PVsyst).

As consequence of the West orientation will be the ballast placement and management a major challenge. Single direction orientated flat roof systems are less strong wind resistant which is a major factor close to the sea at this location and requires more ballast. The K2 modulation gave after several spacing and row adjustments no more warning due to roof overload.

The buildings 6 and 7 from Kühne & Nagel had are associated with two problems related to modulation see *Figure 5. 2.*. Firstly, due to the web-based 2D modulation software from K2 which is based on Google Earth satellite pictures from a bird perspective view. This caused the issue that the roof was awry in the beginning and difficult to size. The issue is due to the combination of roof pitch and bird perspective. After several adjustments to the roof layout and its obstacles modulation for building 6 was possible. The second challenge was related to building 7 and the two building objects integrated as second floor in the roof. As consequence of the eaves of both roofs, the module area got reduced in the first modulation process and the shading area was too unspecific. Through subsequent access to 2D architecture data was it possible to recreate the eves and the corresponding module field. Measurement tools in PVsyst and K2 are thereby crucial to transfer the data. The remaining buildings entailed no major complications in the K2 modulation besides ballast management.

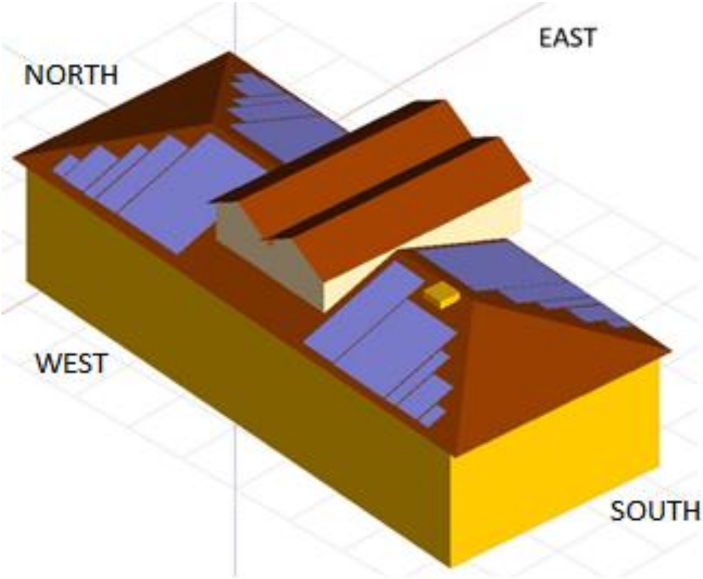
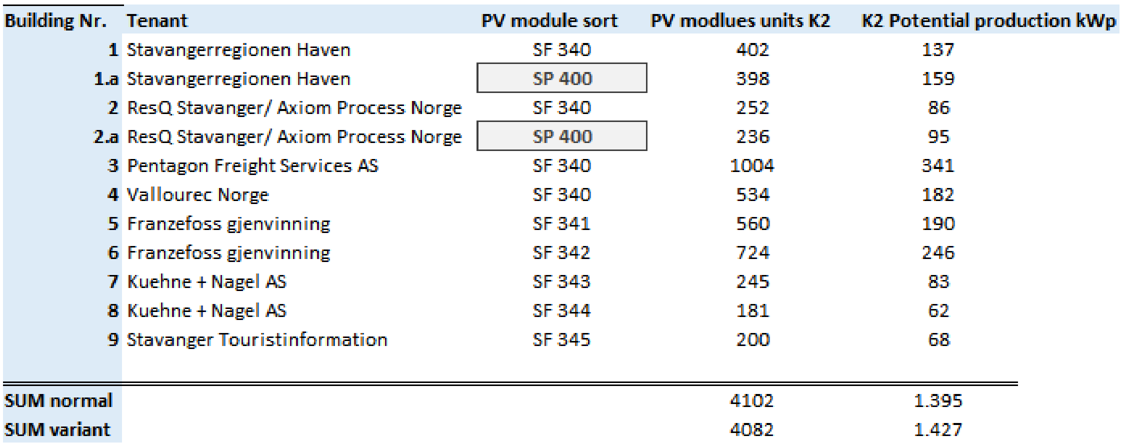


Figure 5.2. Building7- Kuehne + Nagel AS with second floor obstacle (PVsyst).

Therefore, the next step is to explain the main differences which occur through the change of the PV module type. To show this I modulated exemplary an alternative version of building 1 and 2 with the SunPower 400-watt panels. Main differences are of the gathered data is presented in *Table 5. 1.*. The data reveals that by using the 400- watt modules in general a higher production potential is possible. It shows as well that due to a bigger module dimensions the module amount is reduced. In case of building 1 the difference of 4 modules is not vital whereas the difference of 16 modules at building 2 is significantly bigger. The loss of 16 modules offsets therefore a major increase in potential production capacity. Which points out that bigger and more efficient modules not always bring a significant benefit, especially when their price is significant higher, and the roof shape hinders good allocation. In case of building 1 the potential production has increased significantly by 23 kWp which represents an increase of around 16%. It is necessary to evaluate in the further process of this study what the potential benefit of those additional kWp is.



Building Nr.	Tenant	PV module sort	PV modlues units K2	K2 Potential production kWp
1	Stavangerregionen Haven	SF 340	402	137
1.a	Stavangerregionen Haven	SP 400	398	159
2	ResQ Stavanger/ Axiom Process Norge	SF 340	252	86
2.a	ResQ Stavanger/ Axiom Process Norge	SP 400	236	95
3	Pentagon Freight Services AS	SF 340	1004	341
4	Vallourec Norge	SF 340	534	182
5	Franzefoss gjenvinning	SF 341	560	190
6	Franzefoss gjenvinning	SF 342	724	246
7	Kuehne + Nagel AS	SF 343	245	83
8	Kuehne + Nagel AS	SF 344	181	62
9	Stavanger Touristinformation	SF 345	200	68
SUM normal			4102	1.395
SUM variant			4082	1.427

Table 5.1. K2 modulation results, PV amount & production potential (self-created)

The data gathered from K2 gives an electricity production potential outcome of 1.395 kWp for the sum of all systems with the used Solar Fabrik 340-watt panels. The production potential with the variations 1.a & 2.a the production potential rises to 1427 kWp with 20 less PV modules. The lowest production potential has building 8 with 62 kWp and the highest is connected to building 3 with an overall potential of 341 kWp.

The conducted K2 modulation are the technical benchmark and ensure a technical and practical execution of each of the simulated buildings and their roofs. Based on the collected information presented in *Table 5.1.*, the K2 calculation and assembly report, the corresponding module fields can be sized and simulated in PVsyst.[6]

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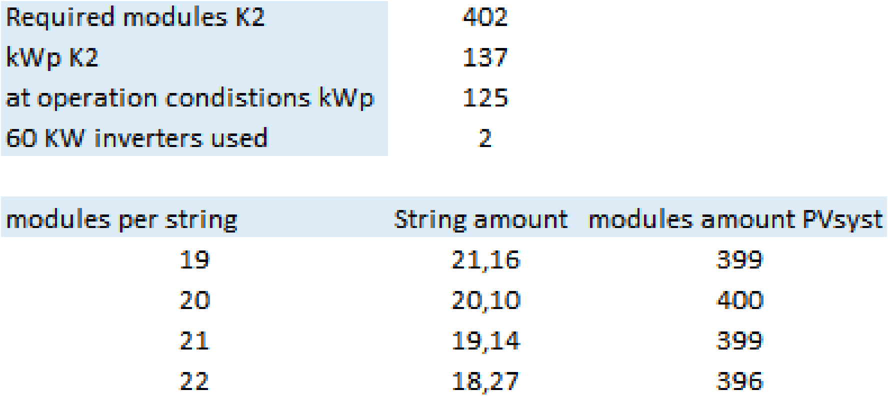
[6] Appendix: K2 report for Building 1 with the 340-watt configuration

5.1.2. PVsyst simulation

The PVsyst simulation delivered for all buildings a great amount of relevant data for future economic evaluations. However, there are two challenges or limitations connected with the use of PVsyst. Firstly, the roof pitch orientation of the designed building and PV system must be the same orientation otherwise the software will have issues connecting those to one system which results in wrong shading and production calculation. To avoid this the roof pitch orientation, must be transferred from the K2 roof design section.

Second challenge is connected to the sizing of the PV system and results in a variance of module amount between K2 and PVsyst. The first step entails to use the kWp data from K2 to decide the capacity and amount of the inverters for the system. Based on the number of inverters and their capacity is set how many cable strings can be connected to the inverter and how many modules can be connected within one string. The following calculation will show the issue:



Required modules K2	402
kWp K2	137
at operation condistions kWp	125
60 KW inverters used	2

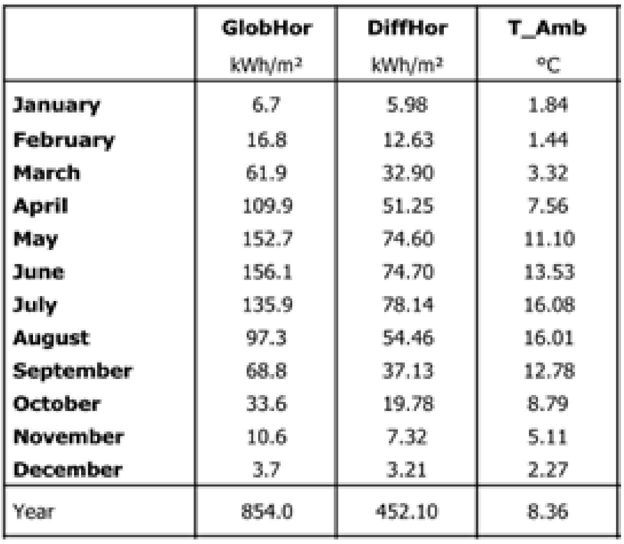
modules per string	String amount	modules amount PVsyst
19	21,16	399
20	20,10	400
21	19,14	399
22	18,27	396

Table 5.2. Building 1-340-watt system sizing (self-created)

As know should be 402 modules placed on the roof of building 1. For this system are used two inverters with a capacity of 60 KW which would be able to cover the electricity input which will fall below 125 kWp due to system and efficiency losses. For those inverters it is most efficient when 20, 21 or 22 modules are connected to one string. For smaller inverters, the amount if 10, 11 or 12 modules. Those are given numbers and cannot be exceeded or undercut in PVsyst due to technical limits of inverter equipment and inefficiency. The existing module amount from K2 402 gets divided by modules per string to give the amount of strings required for the whole system. Since there exists neither half modules nor one third strings as the calculation in *Table 5.2.* suggest for the string amount, does PVsyst use more or to less modules in its simulation. Due to this limit will be a small variance documented in the amount of PV modules between K2 modulation and PVsyst simulation. In the practical implementation this will not be a major issue due to efficiency losses so one additional module per sting can be compensated.

The following section of the PVsyst present first an extensive explanation and analysis of the simulation from the terminal building 1. The second part will focus then on the overall results from all other simulated PV systems. The simulation in PVsyst is based on the irradiance, diffuse, temperature, wind speed and sun irradiation data from the defined location. The simulation is based on the Meteonorm 7.1 data and ensures the correct simulation through historic data.

The Global Horizontal Irradiance (GHI) is the described as the total amount of shortwave radiation received by a horizontal surface defines how much light could be converted into electricity per square meter as given in *Table 5. 3.*. The Diffuse Horizontal Irradiance (DHI) is described as amount of shortwave radiation received through the diffusion of the sky and clouds per square meter. The low GHI and DHI values from November until March indicate that only a small production of electricity through solar PV is possible. For the performance of the system are low temperatures beneficial which is given in Norway throughout the year. Which means that Norwegian summer temperatures will not significantly reduce the output and generate production losses.



	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C
January	6.7	5.98	1.84
February	16.8	12.63	1.44
March	61.9	32.90	3.32
April	109.9	51.25	7.56
May	152.7	74.60	11.10
June	156.1	74.70	13.53
July	135.9	78.14	16.08
August	97.3	54.46	16.01
September	68.8	37.13	12.78
October	33.6	19.78	8.79
November	10.6	7.32	5.11
December	3.7	3.21	2.27
Year	854.0	452.10	8.36

Table 5.3. Building 1-340 irridaanz and temperature simulation (PVsyst report B1)

The normalized production per installed kWp shows that especially in the months of November until March the normalized production is low as consequent of the low GHI and DHI values for those months. *Figure 5.3.* confirms that the normalized production in May exceeds the production of the summer month Juli due to higher GHI and DHI values.

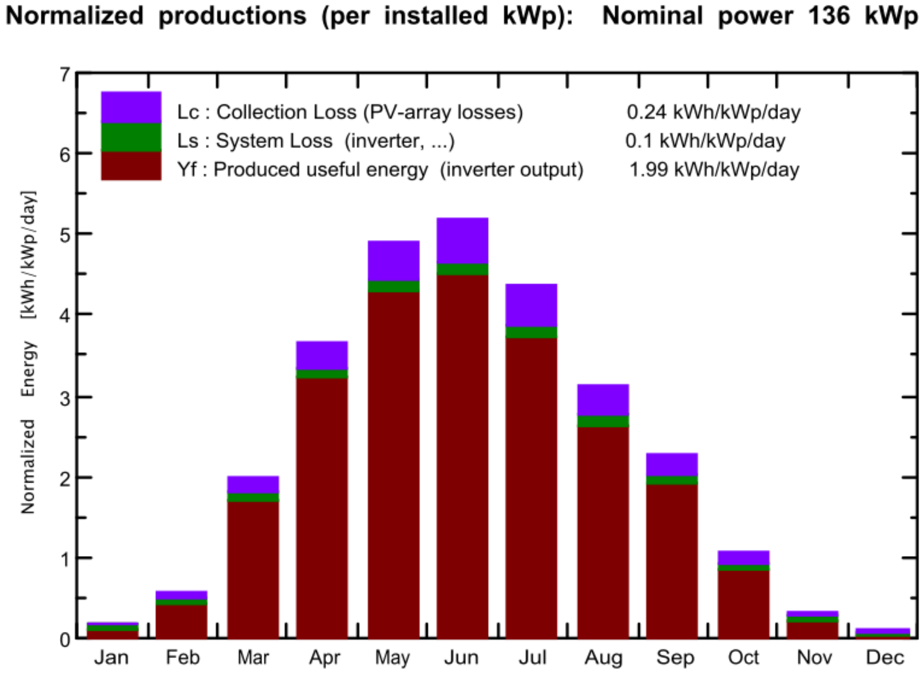
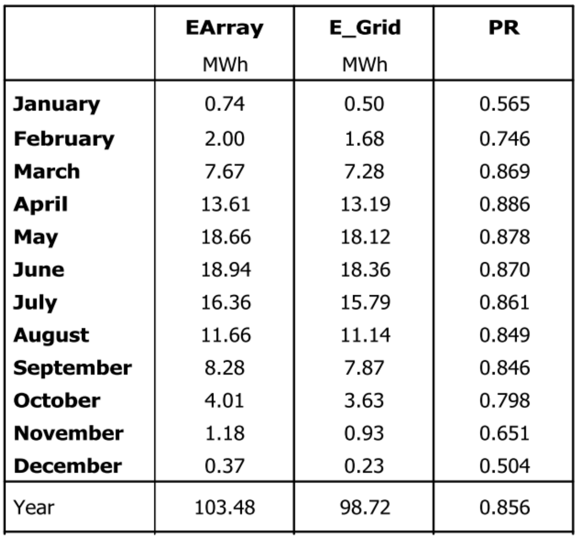


Figure 5.3. Normalized production per kWp (PVsyst report B1).

In respect to losses shows the simulation that the system is well designed, and system losses caused by inverters and cabling are bellow losses that occur through the PV modules and its given orientation on a flat roof.

The simulation of the normalized production per kWp for a one-year period results in a simulated production of 99 MWh and an overall Performance Ratio (PR) and system efficiency of 85,6 % as *Table 5.4.* shows. The PR reflects thereby the impact of overall system losses connected the produced electricity output. The effective energy at the output of the array (EArry) is the energy that is available as output at the modules before losses through cabling and inverters. The actual energy that is available to consumption or sell is the (E_Grid) variable which is the corresponding energy that would be injected into the grid. Base on the values of this variable the study will conduct further analysis and evaluation. The high simulated average Performance Ratio of the system for the months March until September indicates good electricity production. The months November to January reveal a collapse in electricity production and the Performance Ratio due to the absence of enough convertible light and shortwave radiation.



	EArray MWh	**E_Grid** MWh	**PR**
January	0.74	0.50	0.565
February	2.00	1.68	0.746
March	7.67	7.28	0.869
April	13.61	13.19	0.886
May	18.66	18.12	0.878
June	18.94	18.36	0.870
July	16.36	15.79	0.861
August	11.66	11.14	0.849
September	8.28	7.87	0.846
October	4.01	3.63	0.798
November	1.18	0.93	0.651
December	0.37	0.23	0.504
Year	103.48	98.72	0.856

Table 5.4. Monthly simulated EArry, available electricity, system PR (PVsyst report B1).

Three variables can be identified in the loss diagram of the PVsyst report that have a major share on efficiency losses in *Figure 5. 4.*. First is Incidence Angle Modifier (IAM) with 4,72% which "corresponds to the decrease of the irradiance really reaching the PV cells' surface, with respect to irradiance under normal incidence" (PVsyst, n.d.). Those losses are mainly associated with reflections due to the glass cover of PV modules and the incidence angle. Second variable are inverter loss during operation of 4,59% which are directly related to system efficiency. Lastly with a share of 2,24% PV loss due to irradiance level also described as linear shading losses from close PV modules.

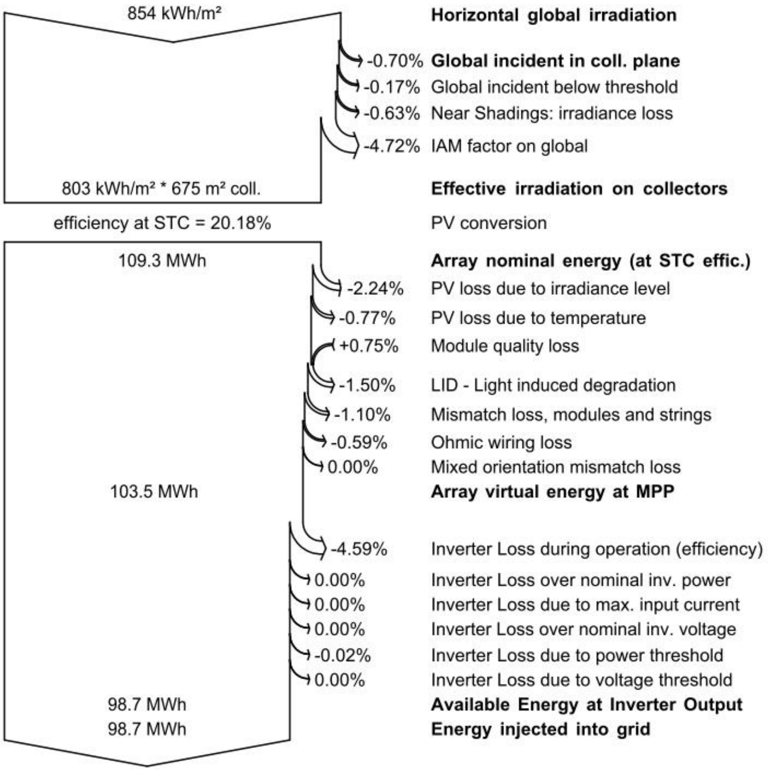
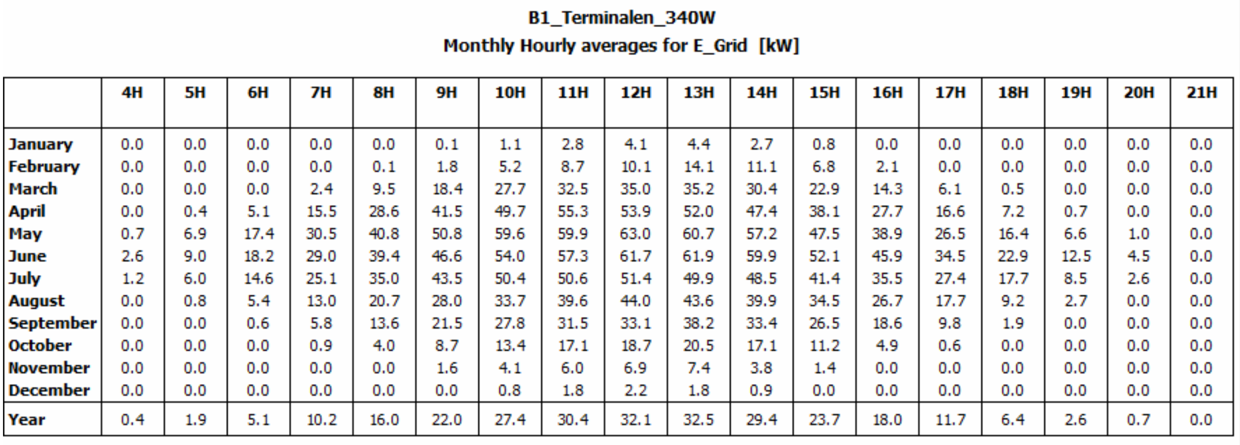


Figure 5.4. Annual loss diagram simulation Terminal 340-watt (PVsyst report B1).

Table 5.5. represents the last part of this section about relevant findings from the terminal building simulation. The data represent the Monthly / Hourly average electricity that is available to consumption or sell. For hours between 21.00 and 3.00 is no production simulated from PVsyst. The numbers indicate that the main production is in the time range of 11.00 – 13.00

where the average production throughout the year is above 30 kW. Highest average production is computed for June at 13.00 with an average of 62 kW. Lowest average production of 0,1 kW is computed for January at 9.00. This production simulation and computed table show exemplary the effect of winter and summer season in the northern hemisphere. With the characteristic of short days with less light in winter and long days with significantly more light in summer. *Table 5.5.* and its format will be in the later phase of the evaluation process merged with consumption data from the terminal building which has the same layout.

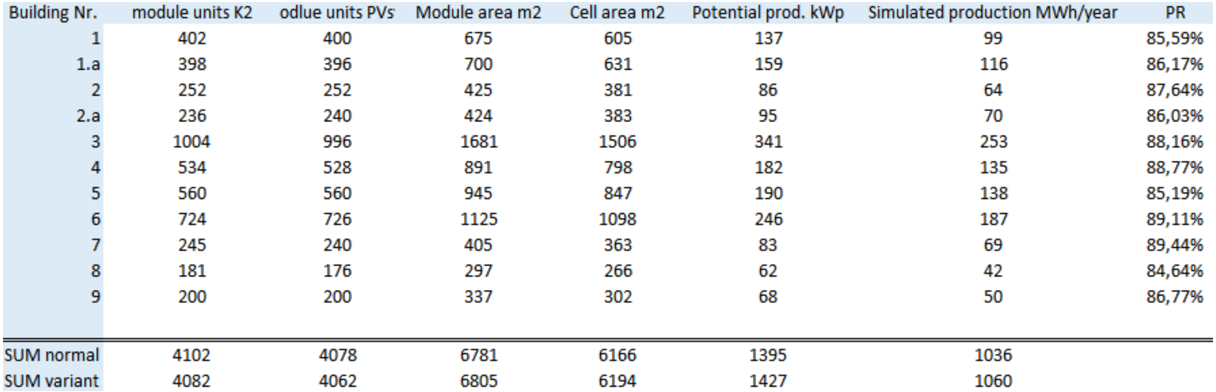


B1_Terminalen_340W
Monthly Hourly averages for E_Grid [kW]

	4H	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H	19H	20H	21H
January	0.0	0.0	0.0	0.0	0.0	0.1	1.1	2.8	4.1	4.4	2.7	0.8	0.0	0.0	0.0	0.0	0.0	0.0
February	0.0	0.0	0.0	0.0	0.1	1.8	5.2	8.7	10.1	14.1	11.1	6.8	2.1	0.0	0.0	0.0	0.0	0.0
March	0.0	0.0	0.0	2.4	9.5	18.4	27.7	32.5	35.0	35.2	30.4	22.9	14.3	6.1	0.5	0.0	0.0	0.0
April	0.0	0.4	5.1	15.5	28.6	41.5	49.7	55.3	53.9	52.0	47.4	38.1	27.7	16.6	7.2	0.7	0.0	0.0
May	0.7	6.9	17.4	30.5	40.8	50.8	59.6	59.9	63.0	60.7	57.2	47.5	38.9	26.5	16.4	6.6	1.0	0.0
June	2.6	9.0	18.2	29.0	39.4	46.6	54.0	57.3	61.7	61.9	59.9	52.1	45.9	34.5	22.9	12.5	4.5	0.0
July	1.2	6.0	14.6	25.1	35.0	43.5	50.4	50.6	51.4	49.9	48.5	41.4	35.5	27.4	17.7	8.5	2.6	0.0
August	0.0	0.8	5.4	13.0	20.7	28.0	33.7	39.6	44.0	43.6	39.9	34.5	26.7	17.7	9.2	2.7	0.0	0.0
September	0.0	0.0	0.6	5.8	13.6	21.5	27.8	31.5	33.1	38.2	33.4	26.5	18.6	9.8	1.9	0.0	0.0	0.0
October	0.0	0.0	0.0	0.9	4.0	8.7	13.4	17.1	18.7	20.5	17.1	11.2	4.9	0.6	0.0	0.0	0.0	0.0
November	0.0	0.0	0.0	0.0	0.0	1.6	4.1	6.0	6.9	7.4	3.8	1.4	0.0	0.0	0.0	0.0	0.0	0.0
December	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.8	2.2	1.8	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Year	0.4	1.9	5.1	10.2	16.0	22.0	27.4	30.4	32.1	32.5	29.4	23.7	18.0	11.7	6.4	2.6	0.7	0.0

Table 5.5. Hourly average electricity Terminal 340-watt (PVsyst advanced simulation).

The PVsyst simulation computes for all Solar PV systems in year one an aggregated production of 1,036 GWh and for the variation 1,059 GWh see *Table 5. 6.*. The lowest simulated production is from building 8 of Kuehne & Nagel with 42 MWh per year and a Performance Ratio of 84,64%. The Performance Ratio is the lowest across all systems due to the East-West orientation of the roof pitch and the corresponding module field. The highest system performance across all projects of 89,44% is from the other Kuehne & Nagel building and its south orientated roof pitch. Building 3 from Pentagon Freight Services AS with the West oriented flat roof system reached a high overall Performance Ratio of 88,16% despite the shading from East. Furthermore, has it the highest simulated production across all projects with 253,29 MWh per year.



Building Nr.	module units K2	odlue units PVs	Module area m2	Cell area m2	Potential prod. kWp	Simulated production MWh/year	PR
1	402	400	675	605	137	99	85,59%
1.a	398	396	700	631	159	116	86,17%
2	252	252	425	381	86	64	87,64%
2.a	236	240	424	383	95	70	86,03%
3	1004	996	1681	1506	341	253	88,16%
4	534	528	891	798	182	135	88,77%
5	560	560	945	847	190	138	85,19%
6	724	726	1125	1098	246	187	89,11%
7	245	240	405	363	83	69	89,44%
8	181	176	297	266	62	42	84,64%
9	200	200	337	302	68	50	86,77%
SUM normal	4102	4078	6781	6166	1395	1036	
SUM variant	4082	4062	6805	6194	1427	1060	

Table 5.6. All projects Summery K2 & PVsyst simulation results (self-created)

The simulation demonstrates for all buildings and systems good results with a low level of overall loses. The simulation shows as well that in PVsyst were 20-24 less modules used in comparison to K2 which must be considered regarding the simulated production. Furthermore, the yearly output can vary from 6-8% due to meteorological changes. For project life simulations the degradation rate of the PV modules from around 0,5-0,8 % must applied annually to compute the corresponding production. The module and cell area in *Table 5.6.* are given to provide a better understanding of the dimensions of the single system simulation where especially building 3 with cell are of 1506 square meter sticks out.

5.2. Consumption & storage evaluation

The consumption of the terminal building is recorded by a total number of 12 electric meters according the online energy overview provided by Stavangerregionen Havn. Only one of the meters will have significant relevance for this study since from that the main consumption is reported. Furthermore, it is the only electric meter that has a tariff contract for big industry which means a consumption of over 80 KVA and additional payment for high effect prices which will play in further analysis a major role. The total electricity consumption 2019 for this meter is reported with an amount of 369.058 kWh. The following energy effect *Figure 5.5.* shows for how many hours within 2019 a certain amount of energy is consumed. The figure shows a reported effect peak consumption of around 90 KW and the lowest consumption of 10 KW for the year 2019. With a closer look into the graph and data it can be said that a consumption above 60 KW is reported for around 700 hours within 2019 which stands for around 8% of the whole year (8760hours). The peaks of 80 KW and 90 KW are even lower as possible to see in the graph. Due to those peak hours above 80 KW a big industry contract must be signed.

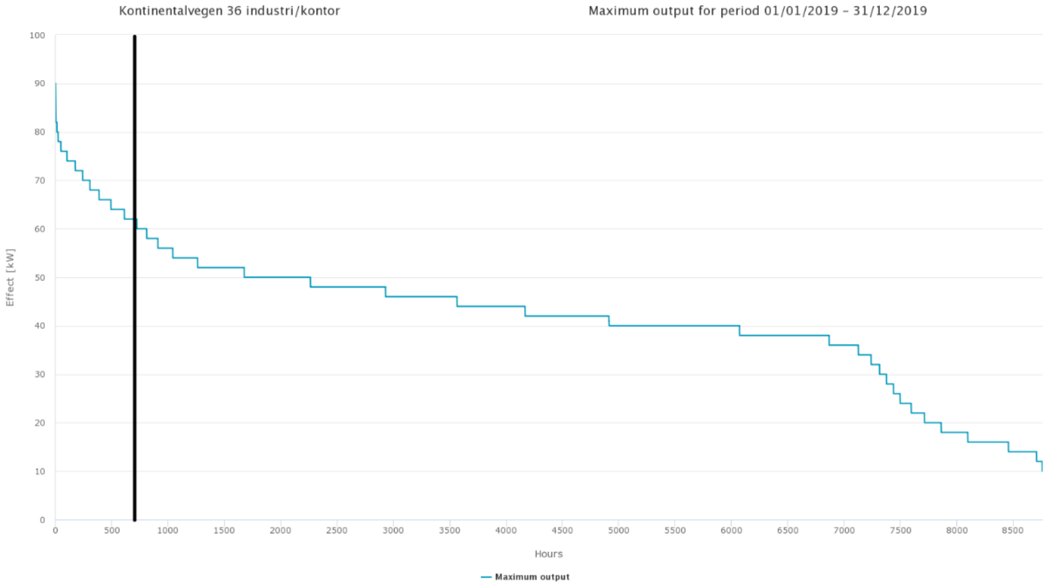


Figure 5.5. Effect distribution 2019 main electric meter (Lyse Elnett user portal Terminal).

For a clearer understanding of the daily consumption distribution are *Figure 5.6.* and *Figure 5.7.* provided which represents two different weeks within 2019 that highlight the consumption distribution and the formation of the peak effects. *Figure 5.6.* represents thereby a week with consumption peaks between 6.00-7.00 and 19.00 during weekdays. Pre and post peak consumption for weekdays are within the range of 40-50 KW. The peak consumption is connected to the arrival and departure of costumers with ferries from the terminal. Therefore, as well as for the weekend is a relatively high energy consumption for the early morning and evening throughout the night reported. Due to closed offices and lower activity at the terminal drops the energy consumption during the day for Saturday and Sundays.

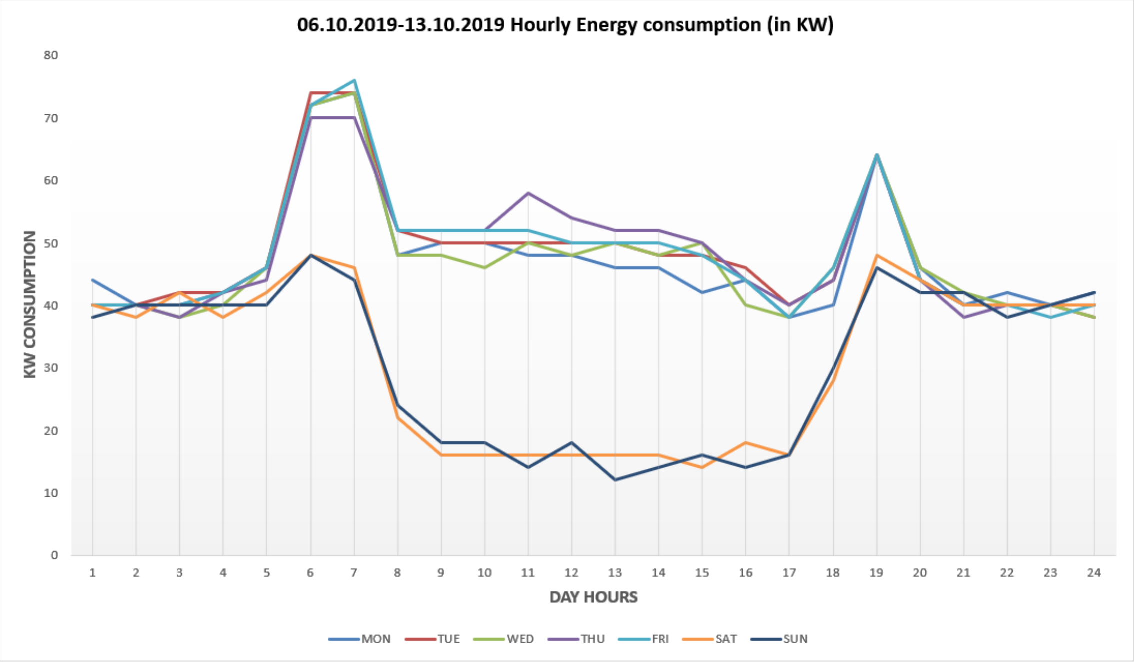


Figure 5.6. 06-13.10.2019 Energy consumption terminal building (self-created).

Figure 5.7. shows a representative week without peak consumption over 60 KW however with several drops and rises which should be discussed. For the big drop of energy consumption from 4.00 until 5.00 no explanation could be found. Rises afterwards are related again to increased human activity before and after ferry arrival and departure and office space activity. Consumption drops from around 16.00 during weekdays are due to end of workday. Further increases and drops through the evening and night are related to ferry activity.

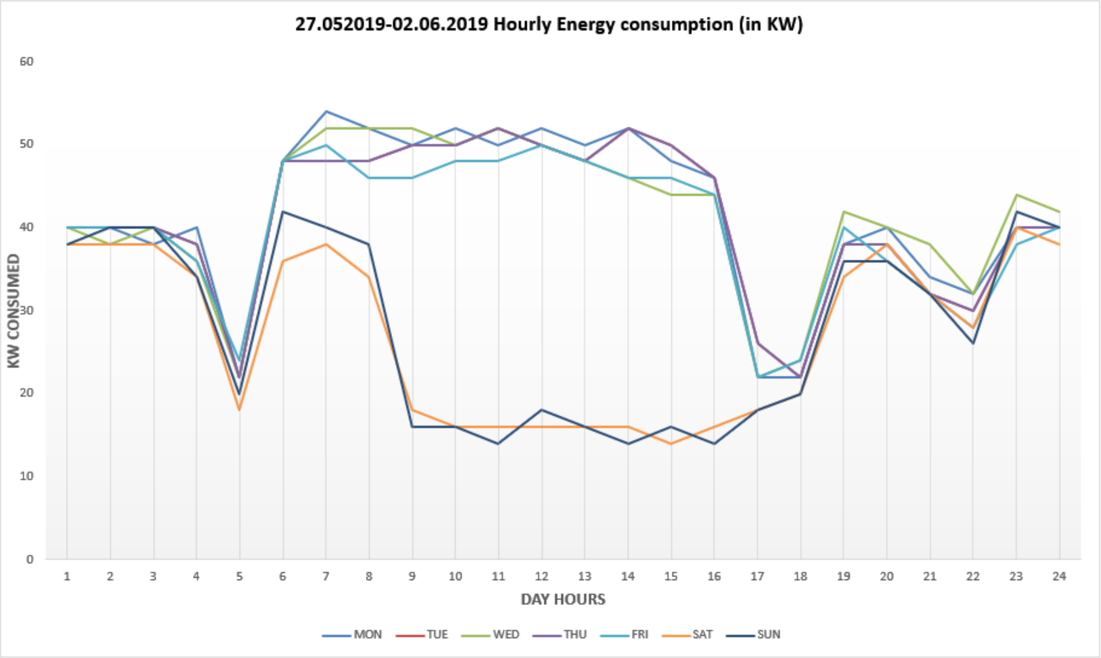


Figure 5.7. 27.05 -02.06. 2019 Energy consumption terminal building (self-created).

To this point it can be summarized that main drivers for energy consumption is related to morning and evening activity from ferry arrival and departure and the activity using the office spaces during the weekdays.

For further analysis are in the Appendix three tables presented.[7] Two of the tables show data about the simulated Monthly/ Hourly production average from PVsyst and the Monthly/ Hourly average electricity consumption data from the terminal building. Both tables now have the same design and can be merged into a third table that represents the results of the subtraction of average production and consumption data. Negative values are green shaded and stand for a higher average simulated production than consumption and possible excess electricity. Red positive values stand for average values above 60 KW and indicate a high or even peak consumption of electricity which were previously identified as a cost driver due to effect consumption tariffs. Those peaks that deviate from average effect consumption of 40-50 KW are besides being more costly a burden for the grid stability. Because the peaks occur in the

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[7] Appendix: Merged simulated production & consumption

early morning and late evening can the installed PV system not contribute directly to load reduction. Additionally, the grid in the morning and evening is already under pressure from the resident sector due to daily morning and evening routines.

Therefore, it is suggested to use electricity storage possibilities which can reduce through peak shaving the load profile and components might be work closer to optimal efficiency level which reduces installation and investments costs. The battery can even increase the performance of the PV system since excess energy can be temporarily stored and later utilized. Another benefit from storage is the possibility to charge the battery during the night where electricity demand is significantly lower. At the next morning, the battery would be able again to supply required electricity to keep the energy demand from the grid at a stable level. This system works likewise good during winter days were most of the high peak demand is recorded.

The decision about the size of the battery is determined by three factors. Firstly, at which level of consumption should be energy supplied by the battery. It should be a level chosen that is not too close to daily average consumption, so the battery is in constant use which reduces the battery lifetime rapidly. Secondly how much energy is required to keep the level which refers to the difference between sought level of consumption and expected consumption. Lastly for how many hours is supply needed to keep the sought level. Referring to information presented previously the battery should not be unnecessary oversized due to the high costs of storage technology. In the case of excess electricity production and an already full battery the electricity can be sold or used to run heat pumps to support the house internal heating or cooling system so save energy and costs there.

The battery size for the terminal building is composed with the following information. Under daily operation the building has an average consumption in the range of 40-50 KW per hour as in the *Figure 5.6. & Figure 5.7.* shown. To avoid over utilisation of the battery an effect level of 60 KW is suggested which still gives some effect variance in the daily operation and increasing average demand due to more activity before using the battery. 60 KW gives enough variance as well on the upper demand side before reaching the critical level of 80 KW to pay extra fees.

The next steps are done by taking a closer look at the consumption data which is given in an hourly resolution for every day in 2019 from Stavagerregionen Havn and the database of Lyse in Excel. The highest hourly reported consumption of 90 KW is measured on the 17.12.2019 at 9.00 and the longest connected period over 60 KW is reported on the 11.12.2019 from 7.00 until 14.00. The same day additionally has the shortest break time between the morning and evening peak which accounted for another 4 hours from 17.00 until 21.00. In total would be 92 KW additional electricity is needed throughout the day to stay at the level of 60 KW. The highest consumption for a single connected period was recorded on the 11.01.2019 with 5 hours and a sum of 88 KW used electricity above 60 KW. Based on this information and data from 2019 the study suggests and minimum storage size of 100 kW/h that the battery is not completely discharged and keep some back up. Under the future aspect of the increasing installation and development of electric car and truck charging infrastructure the battery size must be revised upwards.

The next step looks at what economic consequences the current consumption and peak profile for Stavangerregionen Havn has. Furthermore, what the economic costs the installation of a Solar PV system and battery storage are and which economic benefits could result from such an investment decision.

5.3.Economic evaluation

The electricity invoices from Stavnagerregionen Havn for the terminal building are set together of different variables. First is the fixed grid rent of 18.000 NOK per year, second the variable grid rent with 3,5 øre per kWh in summer and 4,5 øre per kWh in spring/winter.[8] Third the

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[8] 1 NOK = 100 øre

consumption fee of 15,83 øre per kWh. Fourth is the monthly fixed cost for electricity of 37,50 NOK and at last the actual electricity costs with a variable price per kWh. The average price payed for electricity in 2019 was 45,9 øre per kWh and a maximum of 60 øre in January and minimum of 36,8 øre in June. The last costs are the fee to pay by reaching an effect consumption over 80 KW. The cost for the overconsumption in 2019 were 80 NOK per KW and it is informed in the invoices of 2019 that this will increase to 100 NOK per KW. As example has Stavangerregionen Havn paid for the effect of 82 KW the following:

$$82 \text{ KW} * 80 \text{ NOK} = 6.560 \text{ NOK}$$

Additional to all costs described must the tax of 25% be paid to get the total costs for electricity, grid, and effect fee. The corresponding costs for 2019 have a value of 298.003,92 NOK and 372.504,90 NOK including tax.

5.3.1. Production and storage cost savings 2019 evaluation

The first part evaluates savings which can be directly achieved with the installation of Solar PV. The costs that could be directly reduced by the installation of Solar PV are variable grid rent per kWh, the consumption fee per kWh and the actual electricity amount per kWh. In the optimal scenario where 100% of simulated production get consumed throughout the year the savings would account for 55.846 NOK and 69.808 NOK including tax for 2019 simulation. However, the previous analysis has shown that already in the average data a certain amount of excess electricity was produced. Especially for weekends where the terminal consumes significantly less electricity during daytime excess energy production on a sunny Saturday or Sunday will be not consumed.

To show it in an exemplary way the *Figure 5.8.* entails consumption data from the terminal and simulated production data for the same period. The data represents the first weekend in May 2019. The data points out that on the 4. May the terminal have had at 12.00 a consumption of

18 KW whereas PVsyst has simulated a production of 52 KW. This means the system would have had an excess production of 34 KW during that hour.

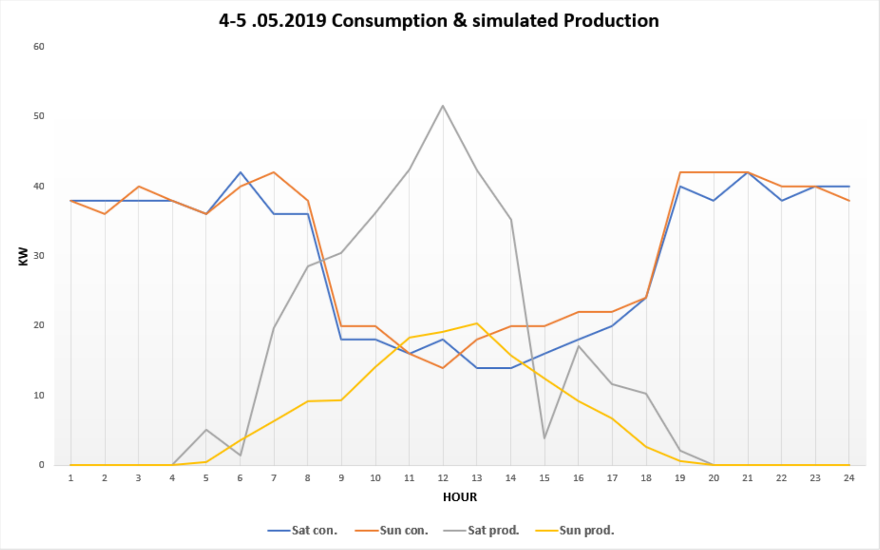


Figure 5.8. 4-5.05.2019 consumption & production Terminal 340- watt (self-created).

Based on this knowledge three options are given. Firstly, the sale of the excess electricity to the grid. When selling electricity, special agreements can be made to get for example 100 øre per kWh produced (Tibber Norge AS , 2020). This means however that to a different time point has to be bought again. For May would be the calculation that 45,8 øre for electricity, 15,83 øre consumption fee and 3,5 øre grid rent must be paid. This makes together 65,13 øre per kWh that get purchased. Subtracted with the earnings of 100 øre per kWh a total 34,87 of profit would be left. Economic wealth can therefore not be generated by selling electricity, which reflects one of the main ideas from the Norwegian government. Furthermore, the sale of more than 100 kWh is not allowed which means large scale production without self-consumption is no option if you are not registered as energy production company.

The second option would be as previously short mentioned the use of the excess electricity to run heat pumps to support the heating or cooling system. The terminal building obtains its heat from the Lyse district heating system LyseNeo. The district heating is thereby run to 51% with bioenergy and 49% fossil gas in 2019 (NFV, 2019). If the excess electricity from the PV system would be utilised to reduce district heating consumption could Stavangerregionen Havn directly reduce their Green House Gas footprint. However, does this analysis and implementation exceed the scope of this study and should in a separate study elaborated.

The third option is the installation of battery storage that could store the excess energy to some degree and consequently a lower amount of energy must be sold. Furthermore, would it give the possibility for peak shaving throughout the whole year that can cut cost related to the effect fee. The cost related to the effect fee were 40.000 NOK and 50.000 NOK including tax for the year 2019.

If this would lead to a 100% self-consumption of produced electricity and zero costs connected to the effect fee 95.846 NOK and 119.805 NOK including taxes could be saved based on the 2019 data. However, since even the battery will be possibly full at one point I will present an alternative calculation where the already known excess energy would be sold other energy bought again to keep the consumption balance which would then express an self-consumption rate of 85%. In total would be then 14.759 kWh due to average production and consumption be listed as overproduction which would have and sell value of 14.759 NOK. In reverse would that mean the purchase of additionally needed electricity would generate costs of 9.059 NOK and 11.325 NOK including tax. This would result in a total revenue of 5.699 NOK and 3.435 after tax. Under the assumption of increasing electricity prices, grid rents and consumption fee the revenue of sold electricity will decrease further.

Under the price regime of 2019, an 85% electricity self-consumption and battery peak shaving a total of 101.546 NOK and 123.243 NOK after tax could be saved with Solar PV and battery storage installation. The same analysis done with the 400-watt module simulation shows that the self-consumption share would drop to 76% due to an average excess production of 24176 kWh. Savings would then increase slightly to 105.160 NOK and 125.406 NOK after tax.

Under the assumption that the battery storage should increase the self-consumption rate in comparison to no storage. Further analysis in the long-term evaluation will consider a self-consumption rate of 95% annually for storage systems. For systems without battery storage will be a self-consumption rate of maximum 85% assumed.

5.3.2. Project Cost

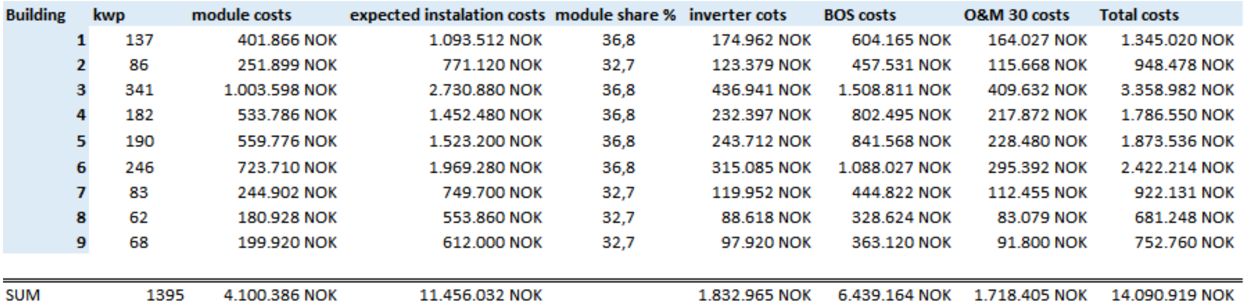
As previously described is the set up from the project costs for Solar PV systems and battery storage technology with several obstacles and limitations connected.

Based on report research and consulting of solar actors in Norway a more realistic share distribution of costs was possible to find. Especially the 2018 report from Multiconsult and Aspan Viak show the costs development in Norway and give good guidance (Multiconsult & Asplan Viak , 2018). However, then the costs of installations have since gone further down as well in Norway. So presents the report 10kr/Wp systems costs whereas the costs today are between 8kr for installations above 100kwp and 9kr/Wp below 100kWp. Based on this information and the actual price for Solar modules from Solar Fabrik and Sun Power a price estimation can be done. Inverter costs have historically not experienced such a price drop, so the values from them are as well more reliable than expected. The system costs must be adjusted for the 400-watt variations since their PV modules are more than two times so expensive. Furthermore, is to recall that costs for equipment in this study are more conservative since companies usually get offered discounted prices.

Under the assumption of a price of 8kr per Wp of the system the terminal building would have first time installation costs of around 1.093.512 NOK. With the given module price of 0,28 € per wp the terminal building has module costs of 401.866 NOK which would be a share of 36,8 percent of the total costs. Inverter account usually for around 8-10% of system costs which would be corresponding to 85.481-109.351 NOK. BOS costs could then in the range of 582.295- 604.165 NOK. Further costs that must be accounted in the later operation are for O&M annually and inverters change after 10-15 years. O&M costs are in Norway calculated as an annually share of 0,5% of the installation costs. This would account for additional costs of 5.467

NOK annually. The lifetime of Solar systems is often calculated with the value of 30 years which correspond to 164.027 NOK O&M costs. However, is this due to the fact that PV modules have mostly a guarantee of 80% performance for those 25 years. It is however observed that the systems can operate 40 to 50 years.

Including the required inverter exchange the overall project costs could account for 1.345.020-1.366.890 NOK. With the decision to add a 100KW battery storage, additional investments for the 30 years of 1.400.000-2.400.000 NOK could be required including a battery exchange. *Table 5.7.* shows the same calculation based on the same assumptions as the previous evaluation with an inverter share of 8% for buildings. Even though the values have been conducted based on several assumptions the values give a better understanding of composition and costs that relate to Solar PV system development.



Building	kwp	module costs	expected instalation costs	module share %	inverter cots	BOS costs	O&M 30 costs	Total costs
1	137	401.866 NOK	1.093.512 NOK	36,8	174.962 NOK	604.165 NOK	164.027 NOK	1.345.020 NOK
2	86	251.899 NOK	771.120 NOK	32,7	123.379 NOK	457.531 NOK	115.668 NOK	948.478 NOK
3	341	1.003.598 NOK	2.730.880 NOK	36,8	436.941 NOK	1.508.811 NOK	409.632 NOK	3.358.982 NOK
4	182	533.786 NOK	1.452.480 NOK	36,8	232.397 NOK	802.495 NOK	217.872 NOK	1.786.550 NOK
5	190	559.776 NOK	1.523.200 NOK	36,8	243.712 NOK	841.568 NOK	228.480 NOK	1.873.536 NOK
6	246	723.710 NOK	1.969.280 NOK	36,8	315.085 NOK	1.088.027 NOK	295.392 NOK	2.422.214 NOK
7	83	244.902 NOK	749.700 NOK	32,7	119.952 NOK	444.822 NOK	112.455 NOK	922.131 NOK
8	62	180.928 NOK	553.860 NOK	32,7	88.618 NOK	328.624 NOK	83.079 NOK	681.248 NOK
9	68	199.920 NOK	612.000 NOK	32,7	97.920 NOK	363.120 NOK	91.800 NOK	752.760 NOK
SUM	1395	4.100.386 NOK	11.456.032 NOK		1.832.965 NOK	6.439.164 NOK	1.718.405 NOK	14.090.919 NOK

Table 5.7. Possible costs distribution for the 9 Buildings-340-watt (self-created).

For the 400-watt projections can be said that inverter costs will be higher since two bigger inverters are needed. However, BOS costs should be slightly lower since less material and hours are required for less panels. Modules cost could account with the current price for 1.70.122 NOK which would be almost 3 times more than the 340-watt installation. With this in mind and the knowledge from the previous section that the 400-watt increased just slightly savings for the 2019 invoices. Additionally, would this generate significantly more excess energy and it is therefore at this stage of the study not recommended to see those modules as beneficial investment and include them in the further analysis.

5.3.3. System long-term profitability evaluation

An often-asked questions when it comes to the installation of renewable sources like solar or wind is if all this is economic profitable and how long it will take. Those kinds of calculations need constant updates since prices for modules, inverters, BOS cost, electricity, grid, inflation rates and subsidies are in constant change. Not only are the prices in change but as well efficiency and performance of the modules and inverters, which effect the electricity output of the system. To control those variables are a challenge which is easy to fail according the report from Multiconsult & Asplan Viak and their analysis of previous studies in Norway often occurred (Multiconsult & Asplan Viak , 2018). Some variables can be easier controlled in this study for example the production projections through PVsyst or the full insights of the costs from 2019 for the terminal building. As above shown are especially costs of the systems a challenge except of PV modules prices which can be used without any issues. Additionally, electricity prices and grid costs projections are assumed to rise however there is also a big variance recorded for the next 30 years. Therefore, it is suggested to use methods from daily business processes like the payback rate.

The payback rate for the solar system would be accruing to this evaluation within the production year 20 as shown in *Figure 5. 9.*. The electricity price projection is orientated on the evaluation from Statnett which shows an possible high price scenario for South-Norway with price increase until 2025 up to 55 øre per kWh and an decrease from that to a level of 45 øre per kWh until 2040 (Bøhnsdalen et al., 2018a). However, are the huge variance in possible prices due to climate changes and annual variation, so were prices in 2019 already 5 øre higher as forecasted. It was assumed 85% of self- consumption at the beginning of operation where excess energy got sold for 100 øre and offset with the costs to buy the same energy for that year. The production degradation is given with 0,8% which would give the panel the required 80% of performance after 25 years (Solar Fabrik , 2020). Considering the lower production annually and the assumption of a electricity consumption increase from 0,8% annually after 13 years no excess energy would be more produced. Grid and consumption fees are hold on a constant price of 0,203 øre per kWh which is the current price. Significant increases for those fees would lead then to a higher value of the produced energy and more savings which would then reduce the payback rate.

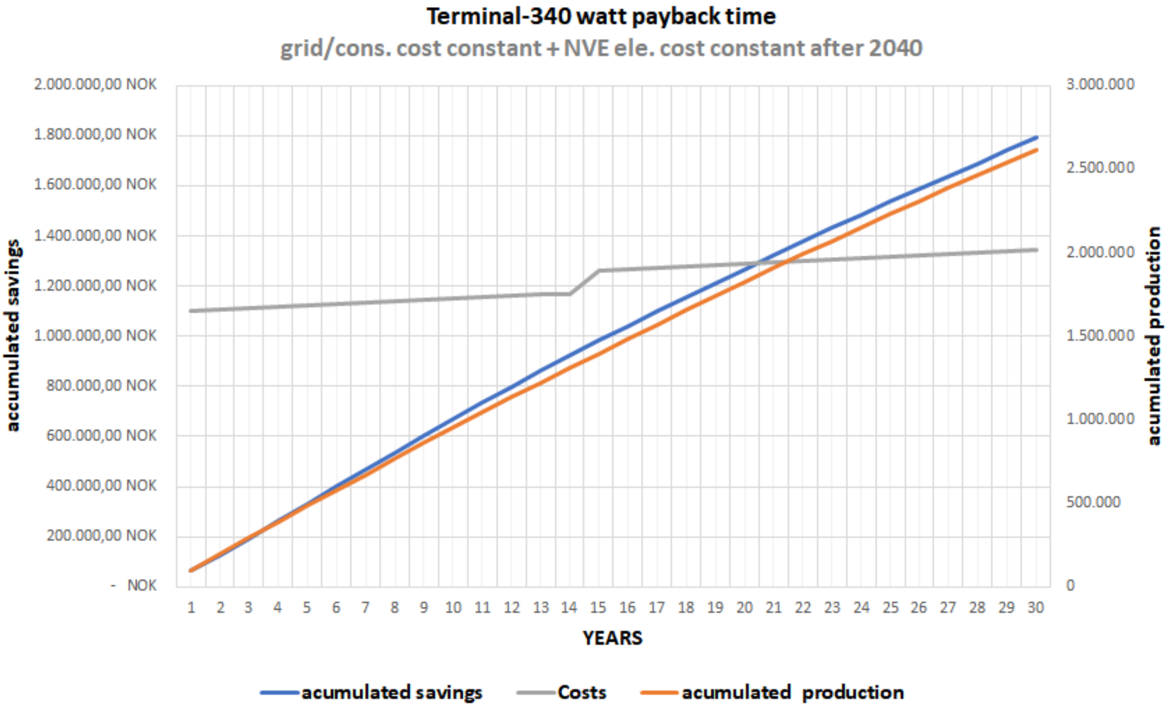


Figure 5.9. Payback time Solar only (self-created).

The following *Figure 5.10.* shows a payback time within year 15 if a project developer could offer 20% lower first time investments due to lower cost purchase agreements with equipment producers and local actors. The starting investments cost would then account for 874.810 NOK. The grid and consumption fees are still constant over the 30 years and would with an increase additionally lower the payback time.

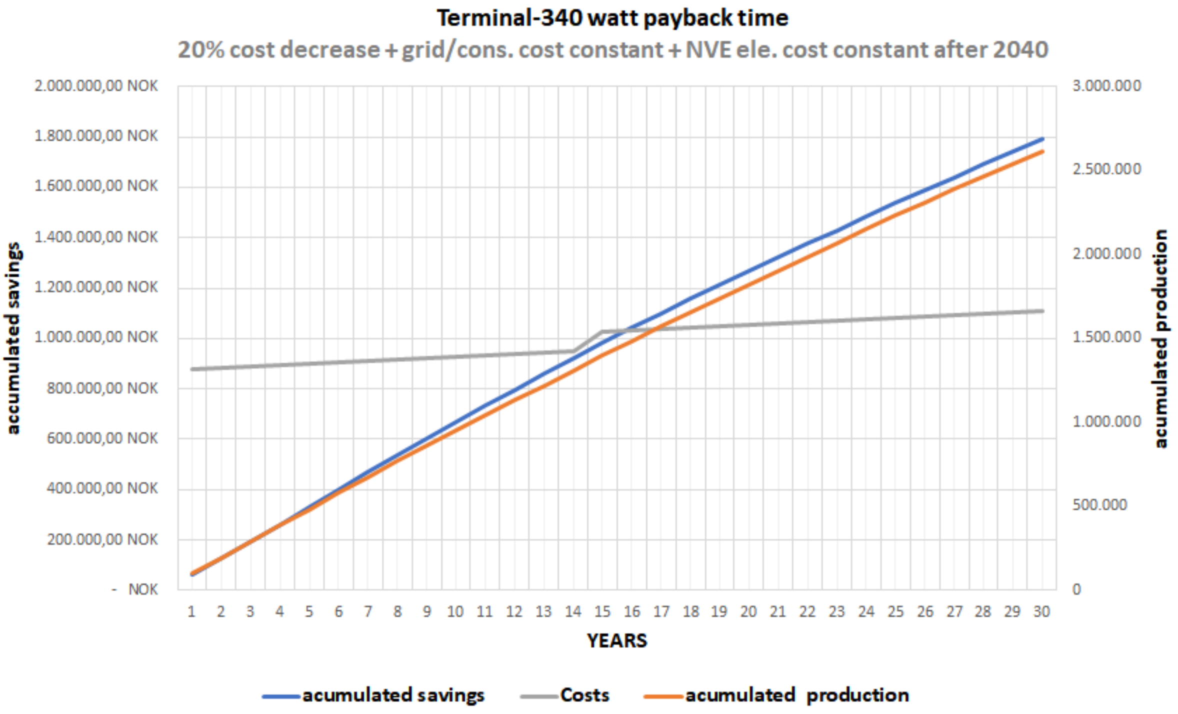


Figure 5.10. Payback time Solar only + 20% investment decrease (self-created).

Under consideration of the utilisation of battery storage *Figure 5.11.* displays a payback time of 26 years. Additionally, is now twice a battery with a value of 700.000 NOK installed represents the lower costs for ISS found in the research previously. Once at the system start and once after 15 years of operation at the same time with the inverter exchange. This is shown by the jump in both cost curves. Under the assumption that the second battery, due to development of the technology, must be much cheaper the payback rate would be significantly shorter. Would the second battery have a cost of 400.000 NOK the payback rate of the whole system would fall to 23 years. Savings of the effect fee are set to 40.000 NOK annually which are the savings according prices 2019 and current prices according to Lyse (Lyse Elnett , 2020). Which means that an increase of the effect fee would lower the payback rate further. The electricity prices, grid and consumption fees are hold at the identical level as in *Figure 5.9. & Figure 5. 10.*. The excess electricity produced was set to 5% percent due to the possibility of full charged battery capacity during sunny weekends. After seven years will be no more overproduction due to module degradation and similar 0,8% energy consumption increase.

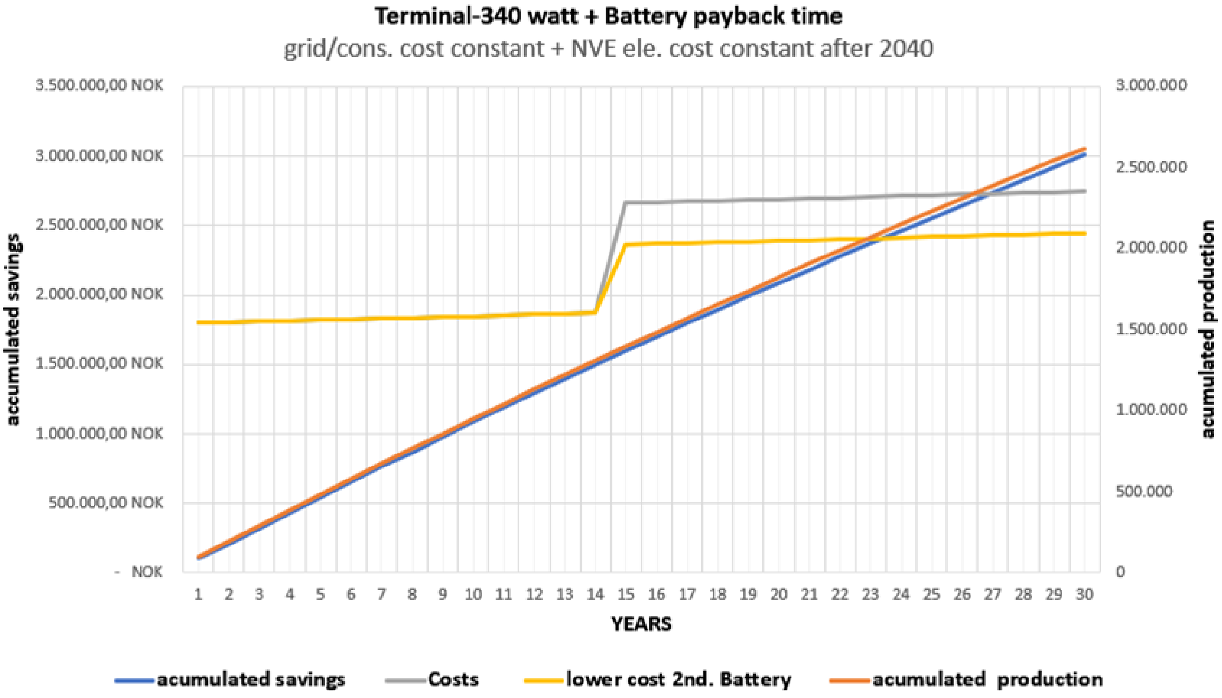


Figure 5.11. Payback time with battery (self-created).

Figure 5.12. shows an adjusted payback time if as previously the first-time investment costs would be 20% lower. All other variables are hold identically to the previous calculation. The payback time for the whole system with the second 700.000 NOK battery would be within year 22. With a battery with costs of 400.000 the playback time would be within the 18 year.

Figure 5.12. highlights furthermore clearly the impact of costs and life cycle of battery storage selected for this example. The first-time investment costs were paid back already within year 13. However, due to the battery change it takes the system again 5 to 9 years to payback dependent on the second battery price. Which shows that the lifecycle and costs of battery storage have big impact on the payback time of such systems.

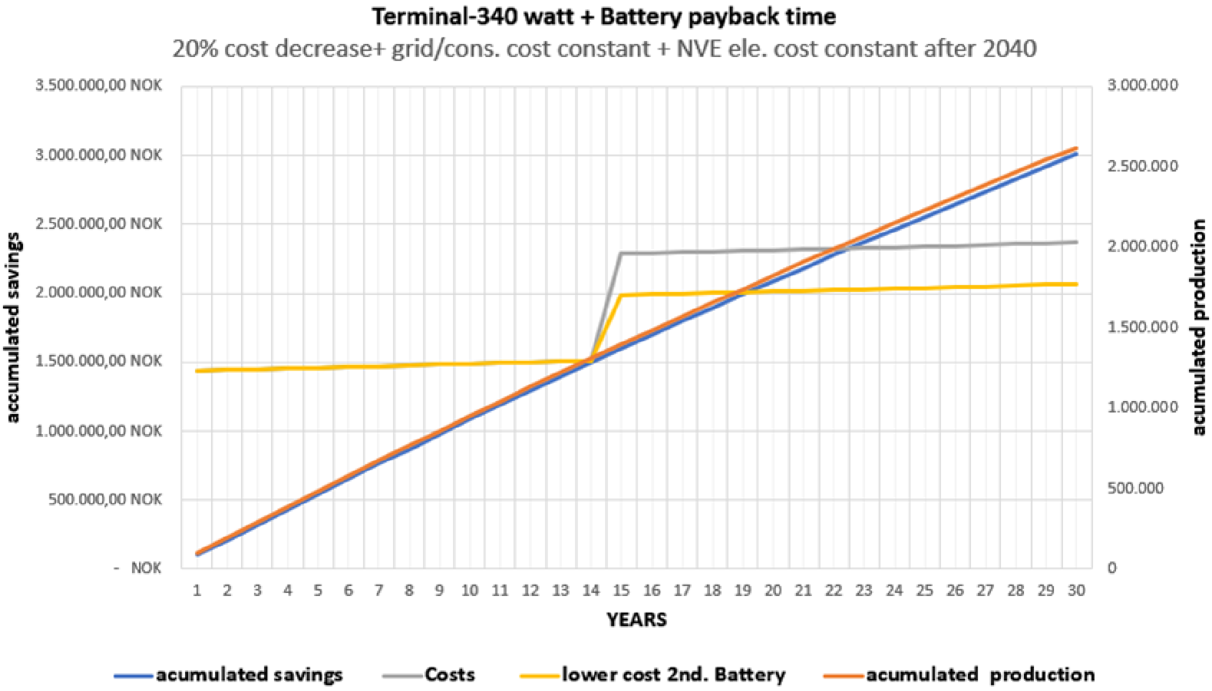


Figure 5.12. Payback time with battery + 20% lower investment costs (self-created)

6. Discussion

The previous chapter revealed, through different stages, important information that is required to discuss in the following section the findings in relation to the research questions and put in context with research previously done. As shown in previous research and actual development observations do solar installations are getting in focus of private and commercial actors in Norway. The story that solar installations have environmental and economic long-term benefits must therefore not be newly told. Moreover, it should be clear that with increasing installations, the industry becomes more established and can provide better and more cost-efficient solutions. However, this study is not part of the installations research from some residential or commercial solar installations in Norway. This study must be seen in the whole picture of Elnett21 and the importance of Elnett21 as large-scale experiment and demonstration project for the region and Norway. Therefore, I discussed first the sub research questions and then shown what it does mean for the overall research question of this study.

6.1.Addressing the first sub-research question

The first sub-research question was: *What is the Solar electricity production potential for the given roofs and buildings?*

As the findings show from the modulation in K2 and simulation in PVsyst, the roofs in Risavika and Stavanger centre have great potential for electricity production and present overall good performance. Which sums in the end up to total installed module area of 7905 square meter and simulated production of 1 GWh in the first year. Taking into consideration that this is just a fraction of possible production in the region, Elnett21 can profit in large scale from that. To point out, just Forus has 2 million square meter building area where a big share could be utilised to produce even more energy if needed (Elnett21, n.d.-a). However, this does not have to mean that the grid load get reduced during peak hours as we can see at the example of the terminal building at Risavika where the peaks occur during times and months were solar production is at a significant lower level compared to summer. The risk for big excess production in late spring and summer must be accounted and taken care of. In summer could this excess electricity become a supportive element for the district heating and cooling network were further greenhouse gases can be reduced. Otherwise would be the solution, as in the case of terminal the integration of battery storage, which would be able to lower throughout the year peak demand, especially in times of low solar irradiation. The example of the terminal building shows what possibilities are given already today to significantly reduce the peak demand. Depending on the future demand of electricity through planes, buses, cars, trucks, and ships must the battery storage system be scaled up significantly. The potential for short travelled produced electricity at Risavika and Elnett21 is given and with additional storage through the winter and nights. The next part will investigate the economic consequences that such a development could have and learn from the findings presented previously.

6.2. Addressing the second sub-research question

The second sub-research question was: *What are the economic costs associated with the Solar PV system and integrated battery storage for the roofs and terminal building?*

The findings have revealed that at first such an investment must be categorised as a long-time investment and even longer with the conservative project cost scenario presented in this study. If however, due to strong increasing consumption and peak hours the costs for grid, effect and consumption fees will increase significantly, a solar PV system and battery storage will not just generate more economic wealth but as well create a more stable grid. As a more stable grid and future reliable system is one of the main goals of Elnett21 this could be a realistic opportunity to do a first step into this direction. So instead of investing huge amount of money into big grid infrastructure that could maybe deliver enough electricity during peak hours and increases the prices for all costumers. The possibility exists to invest as well large amounts of money into a system that could deliver a stable system and get paid back by itself in the long-term and then generates more economic value over time. Especially possible under the aspect that electricity prices and fees shall increase in the future, makes the installation of Solar PV and battery storage a two-win game. Firstly, support of the grid and peak load management and secondly an economic long-term perspective that is positive. Additionally, considering the findings and development presented in the solar and battery review even more cost-efficient and sustainable solutions are not so far from reach if for example Beyonder can convert their ideas for large scale storage as planned. The research has further revealed that cost-efficient solutions are crucial, so has shown that the costs of the super-efficient 400-watt modules burst the project costs and makes and economic performance difficult.

6.3. Addressing the main research question

The key research question for this study was: *How much can Stavangerregionen Havn and Risavika benefit from development of own solar production and installation of battery storage and contribute to Elnett21?*

Stavangerregionen Havn has the production potential to benefit in the long-term already under today’s market conditions from the installation of both the Solar PV installation and battery storage. Even the shown conservative scenario generates value in term of peak reduction from installation start and in the long-term economic evaluation. Dependent on the future price development of electricity, grid costs and from battery technology are benefits increasing under today’s perspective.

Risavika in general has presented on several locations the opportunity to produce a significant amount of electricity that has a potential positive value. Dependent on the height of consumption in the industry there and already existing peak effect fees, solar and battery storage could generate substantial benefits likewise. If consumption would be significantly lower, than their own production benefits would be lower. Under the aspect that Stavangerregionen Havn and Elnett21 announced as well as part of the demonstration project a local micro-grid in which the excess electricity directed to users that have higher demand. This would increase the self-consumption rate of the whole system and lower thereby the grid load. As described earlier in *Section 2.3.2.* this kind of peer-to- peer transfer from electricity are not feasible under the current regulation regime. The goal must therefore be to develop a convincing system that could get an exemption from this regulation to test and demonstrate possible benefits of the local microgrid to change the regulations retrospectively. In connection to theory on experiments presented in this thesis, this situation is characteristic to be explored, tested, and evaluated if even more benefits can be generated through a micro-grid and peer to peer trading. Under such a system and cooperation between different actors could peak and DSM create benefits for a larger area, which is one of the goals of Elnett21. Which brings this discussion to the last part of possible contribution towards Elnett21.

At first it can be said that every kilowatt hour that is locally produced and consumed reduces the load of the grid which is a contribution to Elnett21 even without a micro-grid. Through that the current grid would reach its capacity limit at a higher level of overall consumption which one of the targets under the aspect that consumption will significantly increase. Dependent on the amount of energy produced and consumed at Risavika the support to Forus and Avinor could be even bigger. Under the aspect that on the weekend at Risavika the electricity consumption is lower than the production, excess electricity could be provided to Forus and especially Avinor. There will be the whole year and every day huge amount electricity for future electric busses and aircrafts needed. However, this implies not just an existing electricity peer-to-peer trade within the Risavika area is needed moreover a transfer from electricity from the Risavika area to Avinor and Forus. Under the aspect that this is a large-scale demonstration, innovation and transition experiment, this idea should be one of the subjects to be studied and explored to find synergies and challenges of such a bigger system integration.

6.4.Suggestions for Future Research

In consideration of the fact that peer to peer trading of electricity has no legal mandate at the current time, further opportunities on how the excess energy can be used directly without the need of storage technology should be investigated. Especially, since the benefits of the sale of electricity are low and the amount that can be sold of 100 kWh could be a problem for bigger solar installations.

Therefore, it is suggested to investigate the integration of excess electricity within the district heating and cooling system in the Stavanger region. This could occur under the aspect that through excess electricity and heat pumps the required temperature from district heating get decreased and concluding less natural gas must be consumed. Additionally, heat storage as another storage technology could have benefits, be further explored and be more efficiently utilised. Lund points in his research about a reliable renewable future energy system out:

> “The integration of sectors is very important in 100 percent renewable energy systems to increase fuel efficiency and decrease costs. The first, and most important, step is the integration between the heating and the electricity sectors”(Lund, Mathiesen, Liu, Zhang, & Clark, 2014, p. 223).

Based on this knowledge further research should direct focus on the integration opportunities between electricity and district heating- cooling systems to achieve highest possible synergies and push on with the development of the Stavanger region and Elnett21.

7. Conclusions

The aim and purpose of this thesis was to answer the key research question: *How much can Stavangerregionen Havn and Risavika benefit from development of own solar production and installation of battery storage and contribute to Elnett21?*

The case study of the ferry-terminal was thereby successfully able to provide information about the volume of generation could be possible, how the cost structure and economic long-term scenarios of such a system can look like. Additionally, was the effect of a recommended battery storage on performance, savings and peak shaving explored. Furthermore, was possible to show what the generation potential for other buildings in Risavika could look like and what costs can be associated with a system installation. From those findings was it able to support the idea for more local short-traveled electricity generation as a path to contribute the grid and peak demand challenge and present opportunities with those technologies for the local Elnett21 development.

Point of departure for this thesis is the aim to decarbonize the Norwegian transport sector through an electrification strategy which will consequently challenge local and regional grid infrastructure. Based on this has developed with Elnett21 a regional large-scale demonstration project to find solutions for those challenges. For a better understanding of the importance from large-scale experiments, demonstrations projects and support by politics and society, explored the thesis the theoretical background of the Multi-level perspective, strategic niche management, transition management and Transition experiments. Those gave insight from different perspectives to understand and identify structural, political and technical challenges that occur during a transition.

For a better understanding of the technical challenges and opportunities was performed an extensive review first on the concept of decentralisation and its benefits and challenges as part of the qualitative Mixed Method. Further were explored the Solar PV and battery storage development and the opportunities and challenges that those technologies can bring to a system transition. The findings there revealed an impressive pace under which the technologies makes progress and the increasing dedication towards more sustainable resource saving solutions. Which are however highly necessary due to the increasing need of storage technology to overcome struggles that come with intermittent electricity generation in future decentral systems.

The thesis presented a Mixed-Method research approach that was necessary to understand the techno- economic findings in the socio theoretical perspective. The qualitative findings were able to support the qualitative findings that decentral solutions can have a positive output and impact in Norway under the assumed long-term price, climate and costs variables. Despite the assumed limitations was the research able to show how possible long-term scenarios could look like for Stavangerregionen Havn and Risavika. The qualitative research revealed thereby necessary information about the complexity to perform the techno-economic analysis and under which boundaries and assumptions the evaluation have to occur.

While the unavailability of more consumption data from the other buildings reduces the generalizability towards whole Risavika and Elnett21, does this approach show insights what possibilities exists to reduce the presented load profile though solar and peak demand with battery storage technology. This research clearly illustrates the benefits of Solar and battery technology for commercial utilisation to increase system performance and efficiency, but also raises the question what the opportunities towards the integration of peer to peer trading and direct heating and cooling could be.

References

Abdin, Z., & Khalilpour, K. R. (2019). Chapter 4 - Single and Polystorage Technologies for Renewable-Based Hybrid Energy Systems. In K. R. Khalilpour (Ed.), *Polygeneration with Polystorage for Chemical and Energy Hubs* (pp. 77-131): Academic Press.

Ask, A. O. (2020, July 15). Norske boligbyggelag: Solceller på tak kan redusere behovet for upopulær vindkraft. *Aftenposten.* Retrieved from https://www.aftenposten.no/norge/politikk/i/VbWvjl/norske-boligbyggelag-solceller-paa-tak-kan-redusere-behovet-for-upopul?fbclid=IwAR0zn7L12EeyiwTt4_Dsd6oAEOPXV_Do5Y-ex1aoGzv8OxA5YiBjqYytOGU

Avinor. (2019). Smarte energisystemer på Stavanger Lufthavn Sola en dyd av nødvendighet-Elnett21 som første skritt på forberedelsen til elfly Stavanger Lufthavn. Retrieved from http://docplayer.me/167875376-Smarte-energisystemer-pa-stavanger-lufthavn-sola-en-dyd-av-nodvendighet-elnett21-som-forste-skritt-pa-forberedelsen-til-elfly-stavanger-lufthavn.html

Barchart. (2020). Cobalt Historical Prices. Retrieved from https://www.barchart.com/futures/quotes/U8N19/historical-prices

Bellini, E. (2020). Norwegian tech for Korea's giant floating solar complex. *PV Magazine.* Retrieved from https://www.pv-magazine.com/2020/07/16/norwegian-tech-for-koreas-giant-floating-solar-complex/

Beunen, R., Van Assche, K., & Duineveld, M. (2015). Power/Knowledge as a Driver for Governance Evolution. In R. Beunen, K. Van Assche, & M. Duineveld (Eds.), *Evolutionary Governance Theory-Theory and Applications* (pp. 137-141). Cam: Springer International Publishing.

Beyonder. (n.d.). Game-changing technology. Retrieved from https://www.beyonder.no/technology

BMWi. (2015). *Ein gutes Stück Arbeit Die Energie der Zukunft*. Retrieved from https://www.bmwi.de/Redaktion/DE/Publikationen/Energie/vierter-monitoring-bericht-energie-der-zukunft.pdf?__blob=publicationFile&v=26

Bøhnsdalen, E., Døskeland, I. H., Västermark, K. L., Holmefjord, V., Christiansen, L., & Gunnerød, J. L. (2018a). Langsiktig markedsanalyse: Norden og Europa 2018–2040. *Oslo: Statnett*, 94.

Bøhnsdalen, E., Døskeland, I. H., Västermark, K. L., Holmefjord, V., Christiansen, L., & Gunnerød, J. L. (2018b). *Langsiktig markedsanalyseNorden og Europa 2018–2040*. Retrieved from Oslo: https://www.statnett.no/globalassets/for-aktorer-i-kraftsystemet/planer-og-analyser/langsiktig-markedsanalyse-norden-og-europa-2018-40.pdf

Bryman, A. (2016). *Social research methods* (4th ed. ed.). Oxford.

Casey, T. (2020). Audi e-tron — Top Selling Electric SUV — Will Be Even Topper With V2G EV Charging. Retrieved from https://cleantechnica.com/2020/07/27/audi-e-tron-top-selling-electric-suv-will-be-even-topper-with-v2g-ev-charging/

Child, M., Kemfert, C., Bogdanov, D., & Breyer, C. (2019). Flexible electricity generation, grid exchange and storage for the transition to a 100% renewable energy system in Europe. *Renewable Energy, 139*, 80-101. doi:https://doi.org/10.1016/j.renene.2019.02.077

Chowdhury, M. S., Rahman, K. S., Chowdhury, T., Nuthammachot, N., Techato, K., Akhtaruzzaman, M., . . . Amin, N. (2020). An overview of solar photovoltaic panels' end-of-life material recycling. *Energy Strategy Reviews, 27*, 100431. doi:https://doi.org/10.1016/j.esr.2019.100431

Coley, D. A. (2008). Energy and climate change. *West Sussex, England: John Wiley & Sons, Ltd*, *79*, 80.

Dahl, C. A. (2018, June 8). Nå kan solceller på taket gi bedre rente enn banken. *Aftenposten*. Retrieved from https://www.aftenposten.no/okonomi/i/vmPjJ4/naa-kan-solceller-paa-taket-gi-bedre-rente-enn-banken

Dhundhara, S., Verma, Y. P., & Williams, A. (2018). Techno-economic analysis of the lithium-ion and lead-acid battery in microgrid systems. *Energy Conversion and Management, 177*, 122-142.

Ellingsen, L. A.-W., Hung, C. R., & Strømman, A. H. (2017). Identifying key assumptions and differences in life cycle assessment studies of lithium-ion traction batteries with focus on greenhouse gas emissions. *Transportation Research Part D: Transport and Environment*, *55*, 82-90.

Elnett21. (2020a). Bygger kapasitet for å lagre strøm. Retrieved from https://www.elnett21.no/nyheter/bygger-kapaistet-for-a-lagre-strom

Elnett21. (2020b). Økt etterspørsel for landstrøm. Retrieved from https://www.elnett21.no/nyheter/okt-ettersporsel-for-landstrom

Elnett21. (2020c). Samarbeid om grønn omstilling. Retrieved from https://www.elnett21.no/nyheter/samarbeid-om-gronn-omstilling

Elnett21. (n.d.-a). Lokale mikronett. Retrieved from https://www.elnett21.no/arbeidspakker/lokale-mikronett

Elnett21. (n.d.-b). Stavangerregionen Havn. Retrieved from https://www.elnett21.no/partnere/stavangerregionen-havn

EnergiNorge. (2020). *Fornybarometeret 2020 Status for norsk fornybarnæring*. Retrieved from https://www.energinorge.no/contentassets/ad69933b60e9447cad5e33f31902e598/Fornybarometeret2020.pdf

ENOVA. (2018). About Enova Retrieved from https://www.enova.no/about-enova/

ENOVA. (2019). 210 millioner til framtidens energisystem. Retrieved from https://presse.enova.no/pressreleases/210-millioner-til-framtidens-energisystem-2829629

EuPD. (2020). Companies-TOP BRAND PV. Retrieved from https://www.eupd-research.com/en/cert/companies/#toggle-id-28

Eurostat. (2018). Waste statistics - recycling of batteries and accumulators collected for recycling. Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php/Waste_statistics_-_recycling_of_batteries_and_accumulators

Explorer, T. (n.d.). Next-generation high power energy storage. Retrieved from https://www.theexplorer.no/solutions/next-generation-high-power-energy-storage/

Farjah, A., Ghanbari, T., & Seifi, A. R. (2020). Contribution management of lead-acid battery, Li-ion battery, and supercapacitor to handle different functions in EVs. *International Transactions on Electrical Energy Systems, 30*(1), e12155. doi:10.1002/2050-7038.12155

Figgener, J., Stenzel, P., Kairies, K.-P., Linßen, J., Haberschusz, D., Wessels, O., . . . Sauer, D. U. (2020). The development of stationary battery storage systems in Germany – A market review. *Journal of Energy Storage, 29*, 101153. doi:https://doi.org/10.1016/j.est.2019.101153

Forbes. (2020). How Battery Costs Impact Tesla's Margins: An Interactive Analysis. Retrieved from https://www.forbes.com/sites/greatspeculations/2020/01/13/how-battery-costs-impact-teslas-margins-an-interactive-analysis/#60cc121b5036

Fronius. (n.d.). Fornius Commercial Solutions -It Pays to take a closer look when Choosing an Inverter. Retrieved from https://www.fronius.com/ar-ae/middle-east/photovoltaics/customers-partners/business-owners/commercial-solutions

Geels, F. W. (2005). Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective. *Technological Forecasting and Social Change, 72*(6), 681-696. doi:https://doi.org/10.1016/j.techfore.2004.08.014

Geels, F. W. (2010). Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. *Research Policy, 39*(4), 495-510. doi:10.1016/j.respol.2010.01.022

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental Innovation and Societal Transitions, 1*(1), 24-40. doi:10.1016/j.eist.2011.02.002

Geels, F. W. (2012). A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies. *Journal of Transport Geography, 24*(C), 471-482. doi:10.1016/j.jtrangeo.2012.01.021

Geels, F. W. (2014). Regime Resistance against Low-Carbon Transitions: Introducing Politics and Power into the Multi-Level Perspective. *Theory, Culture & Society, 31*(5), 21-40. doi:10.1177/0263276414531627

Geels, F. W. (2018). Disruption and low-carbon system transformation: Progress and new challenges in socio-technical transitions research and the Multi-Level Perspective. *Energy Research & Social Science, 37*, 224-231. doi:10.1016/j.erss.2017.10.010

Geels, F. W., & Kemp, R. (2007). Dynamics in socio-technical systems: Typology of change processes and contrasting case studies. *Technology in Society, 29*(4), 441-455. doi:https://doi.org/10.1016/j.techsoc.2007.08.009

Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy, 36*(3), 399-417. doi:10.1016/j.respol.2007.01.003

Geels, F. W., & Schot, J. (2010). The Dynamics of Transitions: A Socio- Technical Perspective. In J. Grin, J. Rotmans, & J. Schot (Eds.), *Transitions to Sustainable Development: New Directions in the Study of Long Term Transfromative Change* (pp. 11- 101). New York: Routledge.

Greaker, M., Hagem, C., & Proost, S. (2019). *Vehicle-to-Grid: Impacts on the electricity market and consumer cost of electric vehicles*. Retrieved from https://www.ssb.no/en/forskning/discussion-papers/_attachment/383402?_ts=169fd076c60

GreenZu. (2018). Solar Is a Worthwhile Investment-Breakdown of Solar Panels Cost. Retrieved from https://greenzu.com/cost-of-solar

Griggs, D., Stafford-Smith, M., Gaffney, O., Rockström, J., Öhman, M. C., Shyamsundar, P., . . . Noble, I. (2013). Sustainable development goals for people and planet. *Nature, 495*, 305. doi:10.1038/495305a
https://www.nature.com/articles/495305a#supplementary-information

Gupta, U. (2019). Innovation boosts lithium-ion battery recycling rate to over 80%. *PV Magazine*. Retrieved from https://www.pv-magazine.com/2019/03/25/innovation-boosts-lithium-ion-battery-recycling-rate-to-over-80/

Hentschel, J., Jenssen, Å., Thorsønn Borgen, S., Jarstein, S., & Duus, H. (2018). *Descriptive study of Local Energy Communities*. Retrieved from Oslo: http://webfileservice.nve.no/API/PublishedFiles/Download/201909669/2945443

Hole, J., & Horne, H. (2019). *Batterier vil bli en del av kraftsystemet*. Retrieved from Oslo: http://publikasjoner.nve.no/faktaark/2019/faktaark2019_14.pdf

Horne, H., Buvik, M., & Hole, J. (2019). *Smarte ladesystemer og Vehicle-to-Grid*. Retrieved from http://publikasjoner.nve.no/faktaark/2019/faktaark2019_09.pdf

Huld, T., & Amillo, A. M. G. (2015). Estimating PV Module Performance over Large Geographical Regions: The Role of Irradiance, Air Temperature, Wind Speed and Solar Spectrum. *Energies, 8*(6), 5159-5181. Retrieved from https://www.mdpi.com/1996-1073/8/6/5159

IEA. (2020). Global EV Outlook 2020 - Entering the decade of electric drive? *Technology report — June 2020*. Retrieved from https://www.iea.org/reports/global-ev-outlook-2020

IRENA. (2019a). *Behind-the-meter batteries*. Retrieved from Abu Dahbi: https://irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_BTM_Batteries_2019.pdf

IRENA. (2019b). *Renewable Power Generation Costs in 2019*. Retrieved from Abu Dhabi: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Power_Generation_Costs_2019.pdf

Jaskula, B. W. (2020). Lithium Statistics and Information. *U.S. Geological Survey, Mineral Commodity Summaries.* Retrieved from https://www.usgs.gov/centers/nmic/lithium-statistics-and-information

Johansen, F., & van den Bosch, S. (2017). The scaling-up of Neighbourhood Care: From experiment towards a transformative movement in healthcare. *Futures*, *89*, 60-73. doi:https://doi.org/10.1016/j.futures.2017.04.004

Johnson, E. (2020). Storage Highlights 2020 – Megawatt Winner: Nilar. *PV magazin.* Retrieved from https://www.pv-magazine.com/2020/02/24/storage-highlights-2020-megawatt-winner-nilar/

K2. (2020). K2 Base, Version 2.5.3.0. Retrieved from https://base.k2-systems.com/#!/start

Kemp, R., Loorbach, D., & Rotmans, J. (2007). Transition management as a model for managing processes of co-evolution towards sustainable development. *International Journal of Sustainable Development & World Ecology*, *14*(1), 78-91. doi:10.1080/13504500709469709

Kemp, R., Schot, J., & Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. *Technology Analysis & Strategic Management*, *10*(2), 175-198. doi:10.1080/09537329808524310

Khalilpour, K. R. (2019a). Chapter 2 - The Nexus Era: Toward an Integrated, Interconnected, Decentralized, and Prosumer Future. In K. R. Khalilpour (Ed.), *Polygeneration with Polystorage for Chemical and Energy Hubs* (pp. 27-52): Academic Press.

Khalilpour, K. R. (2019b). Chapter 16 - The Transition From X% to 100% Renewable Future: Perspective and Prospective. In K. R. Khalilpour (Ed.), *Polygeneration with Polystorage for Chemical and Energy Hubs* (pp. 513-549): Academic Press.

Khiareddine, A., Gam, O., & Mimouni, M. F. (2019, 24-26 March 2019). *Techno-economic analysis of the lithium-ion and lead-acid battery in Photovoltaic pumping system.* Paper presented at the 2019 19th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA).

Kim, S. K., Cho, K. H., Kim, J. Y., & Byeon, G. (2019). Field study on operational performance and economics of lithium-polymer and lead-acid battery systems for consumer load management. *Renewable and Sustainable Energy Reviews*, *113*, 109234. doi:https://doi.org/10.1016/j.rser.2019.06.041

Kleven, R., & Leite, S. R. (2018, July 24). Tørke fører til full stans i strømproduksjonen. *NRK*. Retrieved from https://www.nrk.no/trondelag/torke-forer-til-full-stans-i-stromproduksjonen-1.14138107

Klimaavdelingen. (2020). Norge forsterker klimamålet for 2030 til minst 50 prosent og opp mot 55 prosent. Retrieved from https://www.regjeringen.no/no/aktuelt/norge-forsterker-klimamalet-for-2030-til-minst-50-prosent-og-opp-mot-55-prosent/id2689679/

Koestler, V., Østenby, A., Birkeland, C., Arnesen, F., & Haddeland, I. (2019). *Virkningen av klimaendinger på tilsiget til vankraften i Norge- vannkraftverkene i Norge får mer tilsig*. Retrieved from Oslo: http://publikasjoner.nve.no/rapport/2019/rapport2019_50.pdf

Kuzemko, C., Lockwood, M., Mitchell, C., & Hoggett, R. (2016). Governing for sustainable energy system change: Politics, contexts and contingency. *Energy Research & Social Science*, *12*, 96-105. doi:https://doi.org/10.1016/j.erss.2015.12.022

Kvalitetssjef. (2018a). Hva er lønnsomheten for et solcelleanlegg? Retrieved from https://blogg.fusen.no/hva-er-loennsomheten-for-et-solcelleanlegg

Kvalitetssjef. (2018b). Hvorfor bruke solceller i Norge når vi har så mye annen fornybar energi? Retrieved from https://blogg.fusen.no/hvorfor-bruke-solceller-i-norge-naar-vi-har-saa-mye-annen-fornybar-energi

Langhelle, O., Kern, F., Meadowcroft, J., & Rosenbloom, D. (2018). Where are the politics? Situating transition politics within the multi-level perspective. *Manuscript in preparation*, 30.

Levinthal, D. A. (1998). The Slow Pace of Rapid Technological Change: Gradualism and Punctuation in Technological Change. *Industrial and Corporate Change*, *7*(2), 217-247. doi:10.1093/icc/7.2.217

Li, W., Lee, S., & Manthiram, A. (2020). High-Nickel NMA: A Cobalt-Free Alternative to NMC and NCA Cathodes for Lithium-Ion Batteries. *Advanced Materials, 32*(33), 2002718. doi:10.1002/adma.202002718

Loorbach, D. (2007). Transition management. *New mode of governance for sustainable development. Utrecht: International Books*. Retrieved from https://repub.eur.nl/pub/10200/proefschrift.pdf

Lund, H., Mathiesen, B. V., Liu, W., Zhang, X., & Clark, W. W. (2014). Chapter 7 - Analysis: 100 Percent Renewable Energy Systems. In H. Lund (Ed.), *Renewable Energy Systems (Second Edition)* (pp. 185-238). Boston: Academic Press.

Lyse_Elnett. (2020). Nettleie Prisoversikt januar 2020. Retrieved from https://www.lysenett.no/getfile.php/133547-1580386558/Dokumenter/Prishefter%20og%20vilk%C3%A5r/Prishefte%20nettleie%20jan20%20%2802%29.pdf

Mahmud, M. A. P., Huda, N., Farjana, S. H., & Lang, C. (2019). Comparative life cycle environmental impact analysis of lithium-ion (LiIo) and nickel-metal hydride (NiMH) batteries. *Batteries*, *5*(1), 22.

Marcos, J., Marroyo, L., Lorenzo, E., Alvira, D., & Izco, E. (2011). Power output fluctuations in large scale pv plants: One year observations with one second resolution and a derived analytic model. *Progress in Photovoltaics: Research and Applications, 19*(2), 218-227. doi:10.1002/pip.1016

McRae, M. E. (2020). Nickel Statistics and Information. *U.S. Geological Survey, Mineral Commodity Summaries.* Retrieved from https://www.usgs.gov/centers/nmic/nickel-statistics-and-information

Meng, L., Zhang, Y., Wan, X., Li, C., Zhang, X., Wang, Y., . . . Chen, Y. (2018). Organic and solution-processed tandem solar cells with 17.3% efficiency. *Science, 361*(6407), 1094. doi:10.1126/science.aat2612

Ministry_of_Climate_and_Environment. (2020). The Norwegian hydrogen strategy. Retrieved from https://www.regjeringen.no/en/aktuelt/the-norwegian-hydrogen-strategy/id2704774/

Multiconsult_&_Asplan_Viak. (2018). *Solcellesystemer og sol i systemet*. Retrieved from http://solenergiklyngen.no/app/uploads/sites/4/180313-rapport_solkraft-markedsutvikling-2017-endelig.pdf

Neves, S. A., Marques, A. C., & Fuinhas, J. A. (2018). On the drivers of peak electricity demand: What is the role played by battery electric cars? *Energy, 159*, 905-915. doi:https://doi.org/10.1016/j.energy.2018.06.209

Newswire, C. P. (2019). Revolutionary Nilar Hydride® Battery Technology Delivers Unparalleled Energy Storage Life Retrieved from https://www.prnewswire.co.uk/news-releases/revolutionary-nilar-hydride-r-battery-technology-delivers-unparalleled-energy-storage-life-828950185.html

NFV. (2019). Energikilder Risavika 2019. Retrieved from https://www.fjernkontrollen.no/risavika/

Norwegian_Ministry_of_Transport_and_Communications. (2018). *National Transport Plan 2018–2029.* (Meld. St. 33 (2016–2017). Oslo Retrieved from https://www.regjeringen.no/contentassets/7c52fd2938ca42209e4286fe86bb28bd/en-gb/pdfs/stm201620170033000engpdfs.pdf

NVE. (2019a). Solkraft -Solkraft vokser raskt, også i Norge. Retrieved from https://www.nve.no/energiforsyning/kraftproduksjon/solkraft/?ref=mainmenu

NVE. (2019b). Solkraft vokser raskt, også i Norge. Retrieved from https://www.nve.no/energiforsyning/kraftproduksjon/solkraft/?ref=mainmenu

O'cathain, A., Murphy, E., & Nicholl, J. (2008). The quality of mixed methods studies in health services research. *Journal of Health Services Research & Policy, 13*(2), 92-98.

Olaszi, B. D., & Ladanyi, J. (2017). Comparison of different discharge strategies of grid-connected residential PV systems with energy storage in perspective of optimal battery energy storage system sizing. *Renewable and Sustainable Energy Reviews, 75*, 710-718. doi:https://doi.org/10.1016/j.rser.2016.11.046

Olson, D. W. (2020). Graphite Statistics and Information. *U.S. Geological Survey, Mineral Commodity Summaries*. Retrieved from https://www.usgs.gov/centers/nmic/graphite-statistics-and-information

Padoan, F. C. S. M., Altimari, P., & Pagnanelli, F. (2019). Recycling of end of life photovoltaic panels: A chemical prospective on process development. *Solar Energy, 177*, 746-761. doi:https://doi.org/10.1016/j.solener.2018.12.003

Panos, E., Kober, T., & Wokaun, A. (2019). Long term evaluation of electric storage technologies vs alternative flexibility options for the Swiss energy system. *Applied Energy, 252*, 113470. doi:https://doi.org/10.1016/j.apenergy.2019.113470

photovoltaic-software.com. (n.d.). PVSYST (CH) Retrieved from https://photovoltaic-software.com/pv-softwares-calculators/pro-photovoltaic-softwares-download/pvsyst

PVsyst. (n.d). PVsyst Team. Retrieved from https://www.pvsyst.com/pvsyst-team/

PVsyst. (n.d.). Array incidence loss (IAM). Retrieved from https://www.pvsyst.com/help/iam_loss.htm

Revankar, S. T. (2019). Chapter Six - Chemical Energy Storage. In H. Bindra & S. Revankar (Eds.), *Storage and Hybridization of Nuclear Energy* (pp. 177-227): Academic Press.

Review.Solar. (2019). SCORE- SunPower Maxeon 3 Series 390 – 400W. Retrieved from https://review.solar/sunpower-maxeon-3/

Review.Solar. (2020). OVERALL- Solis Solar Inverters Review. Retrieved from https://review.solar/solis-solar-inverter/

Rice-University. (2019). New 'blue-green' solution for recycling world's batteries: Rice scientists show solvent leaches cobalt, lithium for reuse from spent batteries. *ScienceDaily*. Retrieved from https://www.sciencedaily.com/releases/2019/04/190401115823.htm

Romare, M., & Dahllöf, L. (2017). The life cycle energy consumption and greenhouse gas emissions from lithium-ion batteries. *Stockholm. Zugriff am, 23*, 2017.

Rotmans, J. (2005). Societal innovation: between dream and reality lies complexity.

Rotmans, J., & Kemp, R. (2008). Detour Ahead: A Response to Shove and Walker about the Perilous Road of Transition Management. *Environment and Planning A: Economy and Space, 40*(4), 1006-1012. doi:10.1068/a4004let

Scerra, M. (2020). Lithium-ion battery pack costs worldwide between 2011 and 2020 Retrieved from https://www.statista.com/statistics/883118/global-lithium-ion-battery-pack-costs/

Shedd, K. B. (2020). Cobalt Statistics and Information. *U.S. Geological Survey, Mineral Commodity Summaries*. Retrieved from https://www.usgs.gov/centers/nmic/cobalt-statistics-and-information

Siddique, M. B., & Thakur, J. (2020). Assessment of curtailed wind energy potential for off-grid applications through mobile battery storage. *Energy, 201*, 117601. doi:https://doi.org/10.1016/j.energy.2020.117601

Solar_Choice. (2011). Solar power grid price parity through BoS cost reductions. Retrieved from https://www.solarchoice.net.au/blog/solar-power-grid-price-parity-through-bos-cost-reductions/

Solar_Fabirk. (2020). Solar Modules-MonoS2 - Halfcut. Retrieved from https://www.solar-fabrik.de/wp-content/downloads/mono-s2/Mono_S2_330-340W_HC_5BB_web_en.pdf

SSB. (2019). Emissions to air. Retrieved from https://www.ssb.no/en/klimagassn

Statista. (2020). Estimated average battery capacity in electric vehicles worldwide from 2017 to 2025, by type of vehicle Retrieved from https://www.statista.com/statistics/309584/battery-capacity-estimates-for-electric-vehicles-worldwide/

Stavangerregionen_Havn_IKS. (2019). Grønnere havn – landstrøm til offshoreskip. *Stavangerregionen Havn IKS*. Retrieved from https://www.stavangerhavn.no/gronnere-havn-landstrom-til-offshoreskip/

Strielkowski, W. (2020). Chapter 3 - Sustainability off the smart grids. In W. Strielkowski (Ed.), *Social Impacts of Smart Grids* (pp. 55-95): Elsevier.

Suman, Sharma, P., & Goyal, P. (2020). Evolution of PV technology from conventional to nano-materials. *Materials Today: Proceedings, 28*, 1593-1597. doi:https://doi.org/10.1016/j.matpr.2020.04.846

Sun_Power. (2019). Maxeon3- 400w commercial Solar Panel. Retrieved from https://sunpower.maxeon.com/int/sites/default/files/2019-12/sp_MAX3-400-390-370_COM_ds_en_a4_mc4_532420B.v4.pdf

Telaretti, E., & Dusonchet, L. (2017). Stationary battery technologies in the U.S.: Development Trends and prospects. *Renewable and Sustainable Energy Reviews, 75*, 380-392. doi:https://doi.org/10.1016/j.rser.2016.11.003

Tibber_Norge-AS. (2020). Våre avtalevilkår. Retrieved from https://tibber.com/no/avtalevilkar

Torabi, F., & Ahmadi, P. (2020a). Chapter 1 - Battery technologies. In F. Torabi & P. Ahmadi (Eds.), *Simulation of Battery Systems* (pp. 1-54): Academic Press.

Torabi, F., & Ahmadi, P. (2020b). Chapter 9 - Techno-economic assessment of battery systems. In F. Torabi & P. Ahmadi (Eds.), *Simulation of Battery Systems* (pp. 311-352): Academic Press.

Torrens, J. C. L. (2018). *The formation of favourable environments for urban experimantation: Contectual and transformative capacities in Bristol and Medellín.* (Phd Science & Technology Policy studies). University of Sussex, Retrieved from http://sro.sussex.ac.uk/id/eprint/84943/1/Colen%20Ladeia%20Torrens%2C%20Jonas.pdf

Tsiropoulos, I., Tarvydas, D., & Lebedeva, N. (2018). Li-ion Batteries for Mobility and Stationary Storage Applications Scenarios for Costs and Market Growth. *Publications Office of the European Union: Luxembourg*.

Tuv, T.-C. (2019). Kutt alle fire deler av strømprisen. Retrieved from https://blogg.fusen.no/kutt-alle-fire-deler-av-stromprisen

Van den Bosch, S. (2010). *Transition experiments: exploring societal changes towards sustainability*.

van den Bosch, S., & Rotmans, J. (2008). Deepening, Broadening and Scaling up: a Framework for Steering Transition Experiments. Retrieved from http://hdl.handle.net/1765/15812

Veie, C. A., Sidelnikova, M., Skau, S., Koestler, V. J., Aksnes, N. Y., Hole, J., . . . Birkeland, C. (2019). *Analyse og Framskrivning av Kraftproduksjon i Norden til 2040*. Retrieved from Oslo: http://publikasjoner.nve.no/rapport/2019/rapport2019_43.pdf

Vezzoli, C., Ceschin, F., Osanjo, L., M'Rithaa, M. K., Moalosi, R., Nakazibwe, V., & Diehl, J. C. (2018). Distributed/Decentralised Renewable Energy Systems. In *Designing Sustainable Energy for All: Sustainable Product-Service System Design Applied to Distributed Renewable Energy* (pp. 23-39). Cham: Springer International Publishing.

Wang, H., Huang, Y., Huang, C., Wang, X., Wang, K., Chen, H., . . . Li, W. (2019). Reclaiming graphite from spent lithium ion batteries ecologically and economically. *Electrochimica Acta, 313*, 423-431. doi:https://doi.org/10.1016/j.electacta.2019.05.050

Wang, W.-Y., Yen, C. H., Lin, J.-L., & Xu, R.-B. (2019). Recovery of high-purity metallic cobalt from lithium nickel manganese cobalt oxide (NMC)-type Li-ion battery. *Journal of Material Cycles and Waste Management, 21*(2), 300-307. doi:10.1007/s10163-018-0790-x

WWF_&_Accenture. (2016). *Mot lysere Tider- Solkraft i Norge –Fremtidige muligheter for verdiskaping*. Retrieved from https://www.wwf.no/assets/attachments/solkraft_i_norge___fremtidige_muligheter_for_verdiskaping1.pdf

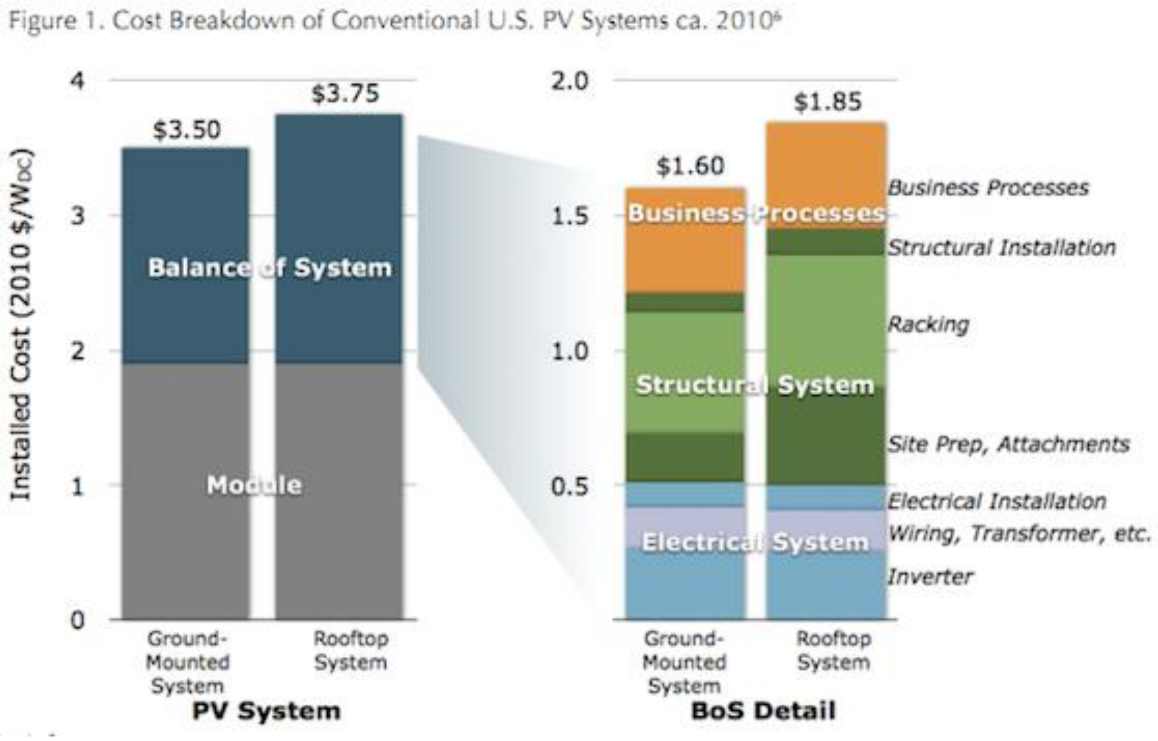
Yadmelat, A. A. (2019). Forvaltning, Drift og Vedlikehold på solenergianlegg. Retrieved from https://blogg.fusen.no/fdv-forvaltning-drift-vedlikehold-solceller-og-solenergianlegg

Yaqoot, M., Diwan, P., & Kandpal, T. C. (2016). Review of barriers to the dissemination of decentralized renewable energy systems. *Renewable and Sustainable Energy Reviews, 58*, 477-490. doi:https://doi.org/10.1016/j.rser.2015.12.224

Zubi, G., Dufo-López, R., Carvalho, M., & Pasaoglu, G. (2018). The lithium-ion battery: State of the art and future perspectives. *Renewable and Sustainable Energy Reviews, 89*, 292-308. doi:https://doi.org/10.1016/j.rser.2018.03.002

Appendix

BOS cost breakdown example



Source:(Solar_Choice, 2011).

Merged simulated generation & consumption data

Simualted production average data (in KW) Termina building 340-watt

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
January	0	0	0	0	0	0	0	0	0	0	1,13	2,82	4,08	4,45	2,73	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	1,82	5,17	8,71	10,10	14,15	11,11	6,79	2,11	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	2,37	9,47	18,43	27,67	32,54	35,04	35,18	30,42	22,90	14,30	6,14	0	0	0	0	0	0
April	0	0	0	0	0	0	5,08	15,53	28,55	41,53	49,69	55,32	53,94	52,02	47,36	38,09	27,71	16,57	7,17	0	0	0	0	0
May	0	0	0	0	0	6,94	17,42	30,51	40,82	50,80	59,57	59,89	62,95	60,69	57,21	47,53	38,87	26,52	16,41	6,57	1,03	0	0	0
June	0	0	0	0	2,56	9,02	18,21	28,99	39,37	46,57	54,04	57,26	61,71	61,93	59,87	52,11	45,86	34,53	22,89	12,49	4,52	0	0	0
July	0	0	0	0	1,17	6,00	14,64	25,11	35,00	43,48	50,39	50,63	51,45	49,89	48,51	41,39	35,53	27,36	17,74	8,54	2,57	0	0	0
August	0	0	0	0	0	0	5,38	12,98	20,66	28,00	33,68	39,62	44,01	43,58	39,92	34,48	26,66	17,70	9,24	2,69	0	0	0	0
September	0	0	0	0	0	0	0	5,79	13,59	21,48	27,80	31,47	33,12	38,22	33,37	26,52	18,61	9,84	1,87	0	0	0	0	0
October	0	0	0	0	0	0	0	0	4,03	8,65	13,36	17,06	18,69	20,46	17,09	11,23	4,91	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	1,56	4,06	5,97	6,85	7,41	3,77	1,39	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	1,77	2,16	1,79	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	1,94	5,14	10,24	16,05	21,97	27,39	30,35	32,11	32,55	29,43	23,68	17,95	11,67	6,35	2,60	0	0	0	0

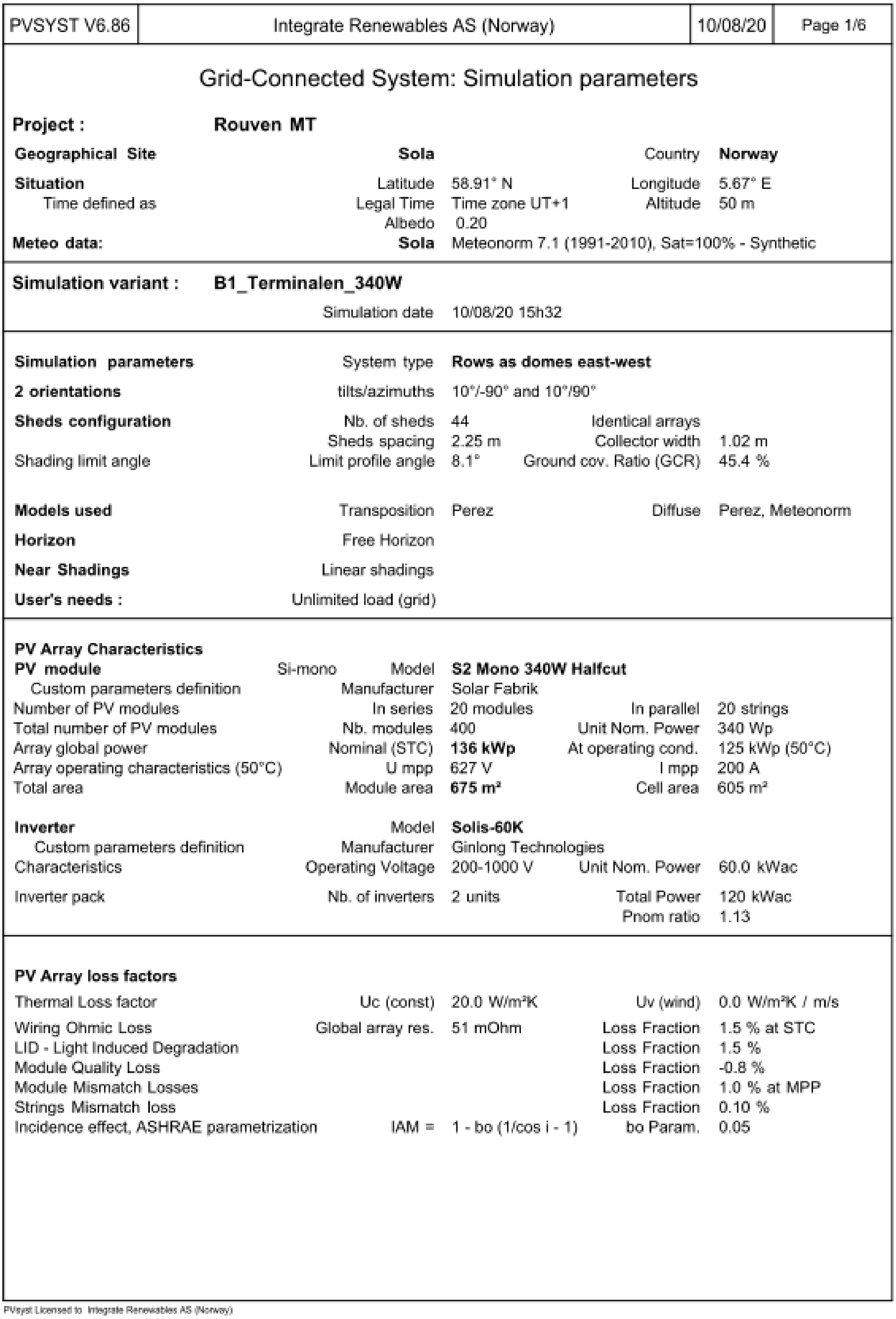
Average consumption data (in KW)Terminal building

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
January	40,2	39,9	39,4	39,5	40,6	43,5	66,0	68,5	69,1	46,6	42,3	41,7	41,7	40,5	39,0	38,0	52,5	47,0	46,1	61,3	61,7	56,7	41,4	40,3
February	40,7	41,1	41,0	40,5	41,0	47,3	70,9	70,9	54,0	41,1	40,2	40,0	39,7	38,7	38,9	37,9	36,2	32,8	48,1	62,9	61,7	57,1	42,1	41,4
March	40,2	40,3	40,1	40,3	41,3	47,3	64,1	50,4	46,3	40,8	41,2	40,6	40,2	39,5	39,2	38,2	36,3	23,2	29,7	61,5	61,8	58,1	41,3	40,3
April	40,2	39,5	39,1	40,5	45,5	57,8	46,9	44,7	39,3	39,7	39,3	39,2	38,4	37,6	36,9	36,0	22,3	22,2	38,1	41,7	53,5	40,1	38,7	39,1
May	38,8	39,0	38,8	39,2	28,6	43,9	44,8	43,8	39,1	39,4	39,1	38,8	38,2	37,5	37,0	35,4	21,5	22,5	37,9	37,2	35,0	36,9	39,2	39,2
June	40,4	40,2	39,9	35,2	23,5	43,5	41,4	41,5	37,5	36,8	36,1	36,9	35,5	35,3	34,7	35,1	26,6	28,2	38,2	32,5	29,5	23,9	40,9	40,5
July	39,4	39,5	39,5	42,5	28,8	44,2	40,1	39,4	38,3	39,0	39,1	39,6	39,0	38,7	37,6	39,9	39,4	39,5	39,0	20,5	16,7	27,7	39,4	39,3
August	38,3	38,3	38,1	43,2	46,2	47,5	38,8	38,3	38,7	38,4	38,2	37,9	37,7	36,7	36,7	39,0	37,6	37,1	37,0	19,7	29,1	39,0	38,5	38,3
September	39,9	39,8	39,7	45,3	49,7	67,0	46,3	39,6	39,1	39,5	39,1	39,6	38,9	38,1	37,8	39,7	38,6	39,7	44,3	40,9	41,9	40,9	40,1	39,9
October	41,0	41,1	40,8	41,4	44,7	62,6	66,0	50,8	42,8	41,9	41,8	41,9	41,2	40,5	39,8	38,1	35,4	47,2	60,1	47,9	42,2	41,2	40,7	41,2
November	41,5	41,9	41,3	41,7	41,5	46,7	66,1	67,3	54,4	42,9	42,1	42,5	42,3	40,9	40,1	39,3	51,1	58,9	60,9	60,3	46,5	42,7	42,2	41,4
December	41,8	42,1	41,6	43,1	43,1	46,1	63,7	64,7	65,5	48,4	39,2	38,7	39,3	38,5	38,0	38,9	59,0	57,1	58,0	58,8	46,1	43,3	41,8	42,0

Merged prduction & consumption average data (in KW)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
January	40,2	39,9	39,4	39,5	40,6	43,5	66,0	68,5	69,1	46,6	41,2	38,9	37,7	36,1	36,2	38,0	52,5	47,0	46,1	61,3	61,7	56,7	41,4	40,3
February	40,7	41,1	41,0	40,5	41,0	47,3	70,9	70,9	54,0	39,3	35,0	31,3	29,6	24,6	27,8	31,1	34,1	32,8	48,1	62,9	61,7	57,1	42,1	41,4
March	40,2	40,3	40,1	40,3	41,3	47,3	64,1	48,0	36,8	22,4	13,6	8,0	5,2	4,3	8,7	15,3	22,0	17,1	29,7	61,5	61,8	58,1	41,3	40,3
April	40,2	39,5	39,1	40,5	45,5	57,8	41,8	29,2	10,7	-1,9	-10,4	-16,1	-15,5	-14,4	-10,4	-2,1	-5,4	5,6	30,9	41,7	53,5	40,1	38,7	39,1
May	38,8	39,0	38,8	39,2	28,6	36,9	27,4	13,3	-1,7	-11,4	-20,5	-21,1	-24,8	-23,1	-20,2	-12,2	-17,4	-4,0	21,5	30,6	34,0	36,9	39,2	39,2
June	40,4	40,2	39,9	35,2	20,9	34,4	23,2	12,5	-1,8	-9,8	-17,9	-20,3	-26,2	-26,7	-25,1	-17,0	-19,3	-6,3	15,3	20,0	25,0	23,9	40,9	40,5
July	39,4	39,5	39,5	42,5	27,7	38,2	25,4	14,2	3,3	-4,5	-11,3	-11,0	-12,5	-11,2	-10,9	-1,5	3,8	12,1	21,2	11,9	14,1	27,7	39,4	39,3
August	38,3	38,3	38,1	43,2	46,2	47,5	33,5	25,3	18,1	10,4	4,5	-1,7	-6,3	-6,9	-3,2	4,5	11,0	19,4	27,7	17,0	29,1	39,0	38,5	38,3
September	39,9	39,8	39,7	45,3	49,7	67,0	46,3	33,8	25,5	18,1	11,3	8,1	5,8	-0,1	4,4	13,2	20,0	29,9	42,4	40,9	41,9	40,9	40,1	39,9
October	41,0	41,1	40,8	41,4	44,7	62,6	66,0	50,8	38,8	33,3	28,4	24,8	22,5	20,0	22,7	26,8	30,5	47,2	60,1	47,9	42,2	41,2	40,7	41,2
November	41,5	41,9	41,3	41,7	41,5	46,7	66,1	67,3	54,4	41,3	38,1	36,5	35,4	33,5	36,3	37,9	51,1	58,9	60,9	60,3	46,5	42,7	42,2	41,4
December	41,8	42,1	41,6	43,1	43,1	46,1	63,7	64,7	65,5	48,4	39,2	36,9	37,1	36,7	38,0	38,9	59,0	57,1	58,0	58,8	46,1	43,3	41,8	42,0

PVsyst simulation report terminal building 340-watt



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Grid-Connected System: Simulation parameters

Project :	**Rouven MT**			
Geographical Site		**Sola**	Country	**Norway**
Situation	Latitude	58.91° N	Longitude	5.67° E
Time defined as	Legal Time	Time zone UT+1	Altitude	50 m
	Albedo	0.20		
Meteo data:	**Sola**	Meteonorm 7.1 (1991-2010), Sat=100% - Synthetic		

Simulation variant :	**B1_Terminalen_340W**			
	Simulation date	10/08/20 15h32		

Simulation parameters	System type	**Rows as domes east-west**		
2 orientations	tilts/azimuths	10°/-90° and 10°/90°		
Sheds configuration	Nb. of sheds	44	Identical arrays	
	Sheds spacing	2.25 m	Collector width	1.02 m
Shading limit angle	Limit profile angle	8.1°	Ground cov. Ratio (GCR)	45.4 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics

PV module	Si-mono	Model	**S2 Mono 340W Halfcut**		
Custom parameters definition		Manufacturer	Solar Fabrik		
Number of PV modules		In series	20 modules	In parallel	20 strings
Total number of PV modules		Nb. modules	400	Unit Nom. Power	340 Wp
Array global power		Nominal (STC)	**136 kWp**	At operating cond.	125 kWp (50°C)
Array operating characteristics (50°C)		U mpp	627 V	I mpp	200 A
Total area		Module area	**675 m²**	Cell area	605 m²
Inverter		Model	**Solis-60K**		
Custom parameters definition		Manufacturer	Ginlong Technologies		
Characteristics		Operating Voltage	200-1000 V	Unit Nom. Power	60.0 kWac
Inverter pack		Nb. of inverters	2 units	Total Power	120 kWac
				Pnom ratio	1.13

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	51 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	1.5 %
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

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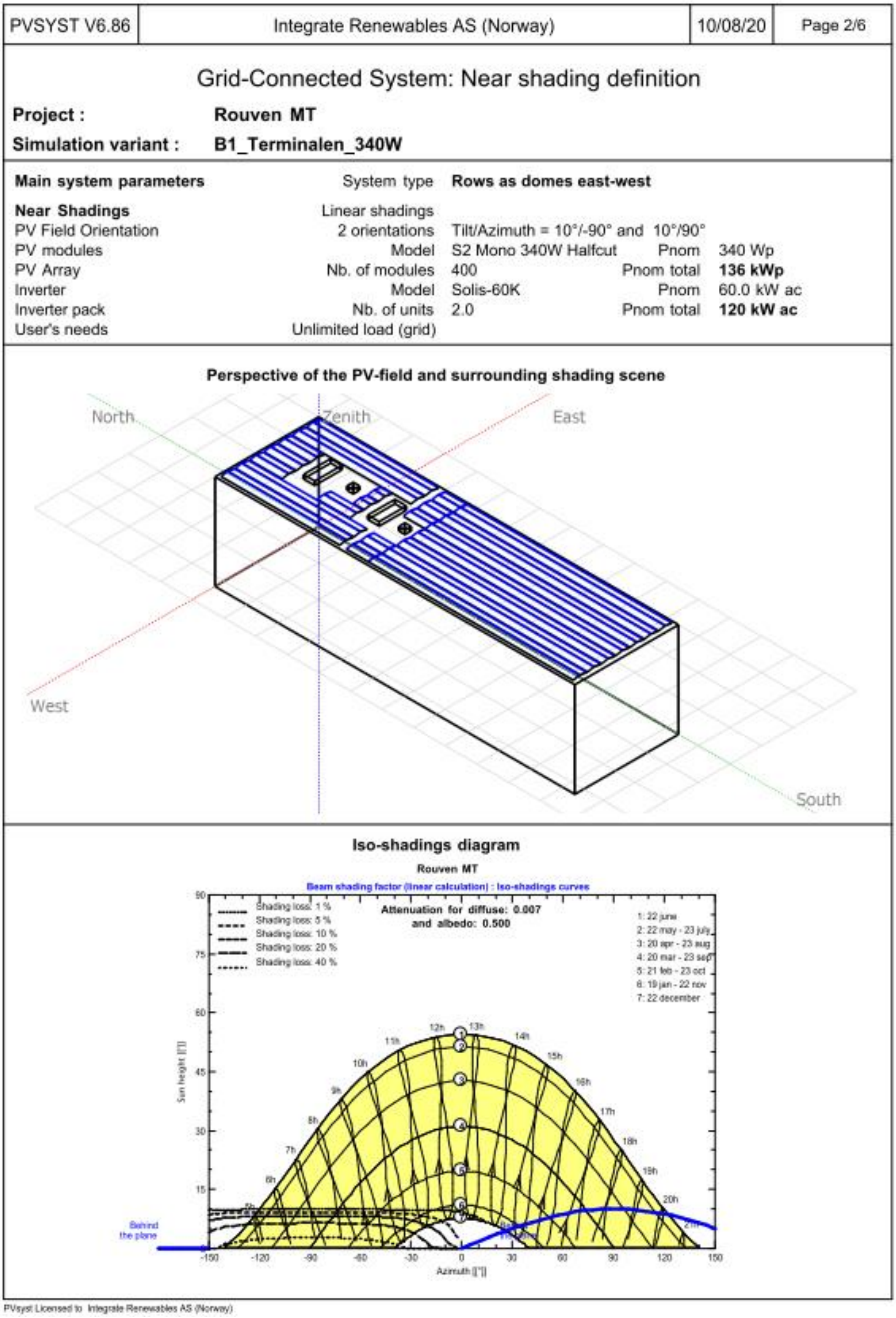

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Grid-Connected System: Near shading definition

Project : **Rouven MT**

Simulation variant : **B1_Terminalen_340W**

Main system parameters	System type	**Rows as domes east-west**		
Near Shadings	Linear shadings			
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/-90° and 10°/90°		
PV modules	Model	S2 Mono 340W Halfcut	Pnom	340 Wp
PV Array	Nb. of modules	400	Pnom total	**136 kWp**
Inverter	Model	Solis-60K	Pnom	60.0 kW ac
Inverter pack	Nb. of units	2.0	Pnom total	**120 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene

Iso-shadings diagram

Rouven MT

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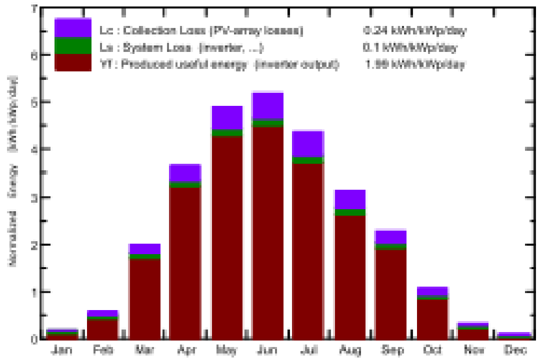
Grid-Connected System: Main results

Project : **Rouven MT**
Simulation variant : **B1_Terminalen_340W**

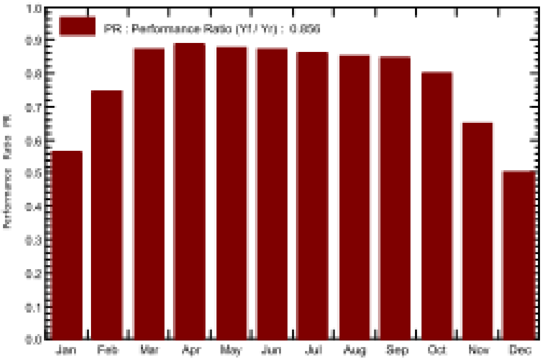
Main system parameters	System type	**Rows as domes east-west**		
Near Shadings	Linear shadings			
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/-90° and 10°/90°		
PV modules	Model	S2 Mono 340W Halfcut	Pnom	340 Wp
PV Array	Nb. of modules	400	Pnom total	**136 kWp**
Inverter	Model	Solis-60K	Pnom	60.0 kW ac
Inverter pack	Nb. of units	2.0	Pnom total	**120 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**98.72 MWh/year**	Specific prod.	726 kWh/kWp/year
	Performance Ratio PR	85.59 %		

Normalized productions (per installed kWp): Nominal power 136 kWp



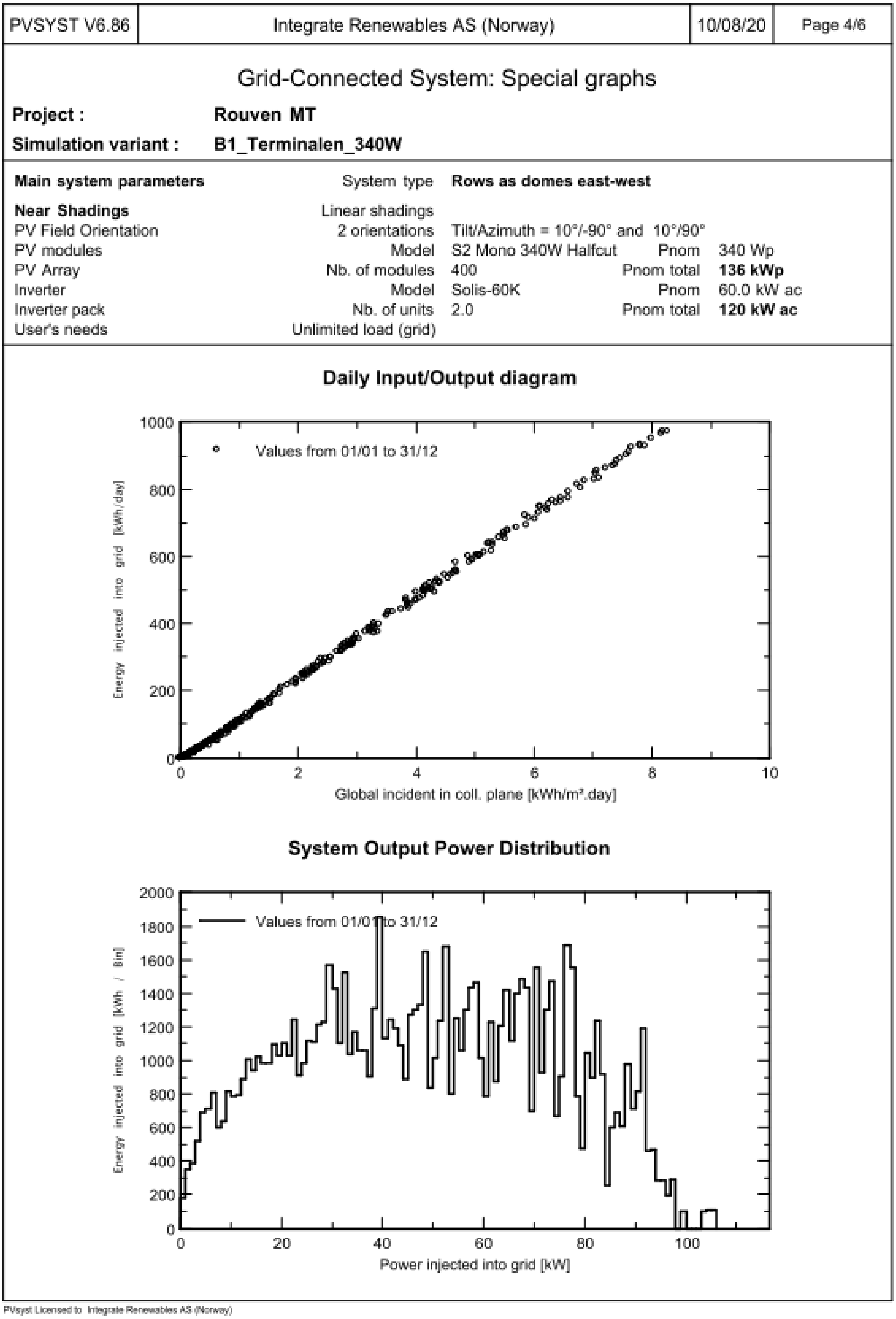
Performance Ratio PR



B1_Terminalen_340W
Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	6.7	5.98	1.84	6.5	6.0	0.74	0.50	0.565
February	16.8	12.63	1.44	16.6	15.3	2.00	1.68	0.746
March	61.9	32.90	3.32	61.6	57.6	7.67	7.28	0.869
April	109.9	51.25	7.56	109.4	103.6	13.61	13.19	0.886
May	152.7	74.60	11.10	151.7	144.6	18.66	18.12	0.878
June	156.1	74.70	13.53	155.2	148.1	18.94	18.36	0.870
July	135.9	78.14	16.08	134.9	128.5	16.36	15.79	0.861
August	97.3	54.46	16.01	96.5	91.6	11.66	11.14	0.849
September	68.8	37.13	12.78	68.4	64.1	8.28	7.87	0.846
October	33.6	19.78	8.79	33.4	31.0	4.01	3.63	0.798
November	10.6	7.32	5.11	10.5	9.4	1.18	0.93	0.651
December	3.7	3.21	2.27	3.4	3.1	0.37	0.23	0.504
Year	854.0	452.10	8.36	848.1	802.9	103.48	98.72	0.856

Legends:				
	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T_Amb	T amb.	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio



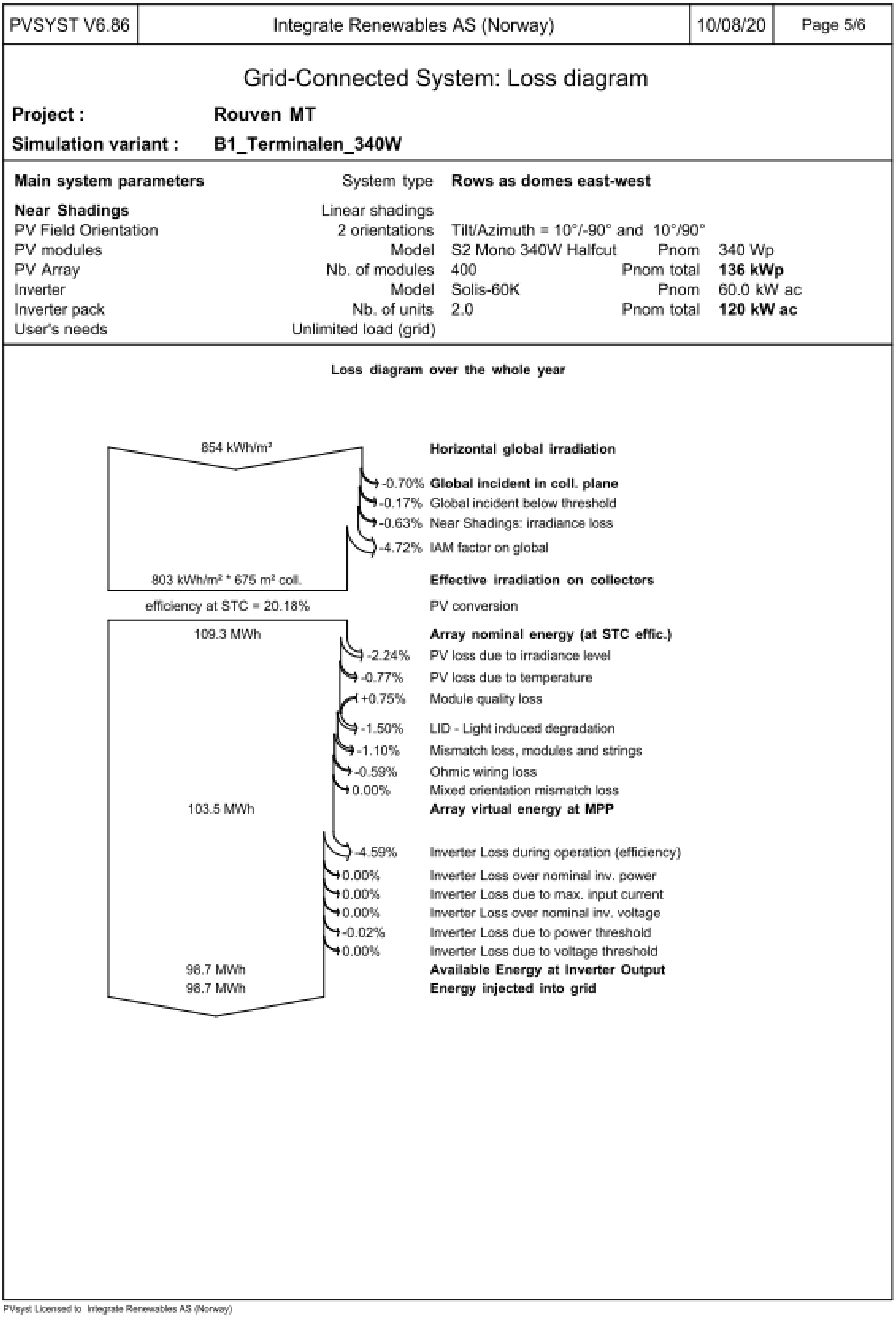
Grid-Connected System: Special graphs

Project : **Rouven MT**
Simulation variant : **B1_Terminalen_340W**

Main system parameters	System type	**Rows as domes east-west**		
Near Shadings	Linear shadings			
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/-90° and 10°/90°		
PV modules	Model	S2 Mono 340W Halfcut	Pnom	340 Wp
PV Array	Nb. of modules	400	Pnom total	**136 kWp**
Inverter	Model	Solis-60K	Pnom	60.0 kW ac
Inverter pack	Nb. of units	2.0	Pnom total	**120 kW ac**
User's needs	Unlimited load (grid)			

Daily Input/Output diagram

System Output Power Distribution



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Grid-Connected System: Loss diagram

Project : **Rouven MT**

Simulation variant : **B1_Terminalen_340W**

Main system parameters	System type	**Rows as domes east-west**		
Near Shadings	Linear shadings			
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/-90° and 10°/90°		
PV modules	Model	S2 Mono 340W Halfcut	Pnom	340 Wp
PV Array	Nb. of modules	400	Pnom total	**136 kWp**
Inverter	Model	Solis-60K	Pnom	60.0 kW ac
Inverter pack	Nb. of units	2.0	Pnom total	**120 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year

854 kWh/m²		**Horizontal global irradiation**
	-0.70%	**Global incident in coll. plane**
	-0.17%	Global incident below threshold
	-0.63%	Near Shadings: irradiance loss
	-4.72%	IAM factor on global
803 kWh/m² * 675 m² coll.		**Effective irradiation on collectors**
efficiency at STC = 20.18%		PV conversion
109.3 MWh		**Array nominal energy (at STC effic.)**
	-2.24%	PV loss due to irradiance level
	-0.77%	PV loss due to temperature
	+0.75%	Module quality loss
	-1.50%	LID - Light induced degradation
	-1.10%	Mismatch loss, modules and strings
	-0.59%	Ohmic wiring loss
	0.00%	Mixed orientation mismatch loss
103.5 MWh		**Array virtual energy at MPP**
	-4.59%	Inverter Loss during operation (efficiency)
	0.00%	Inverter Loss over nominal inv. power
	0.00%	Inverter Loss due to max. input current
	0.00%	Inverter Loss over nominal inv. voltage
	-0.02%	Inverter Loss due to power threshold
	0.00%	Inverter Loss due to voltage threshold
98.7 MWh		**Available Energy at Inverter Output**
98.7 MWh		**Energy injected into grid**

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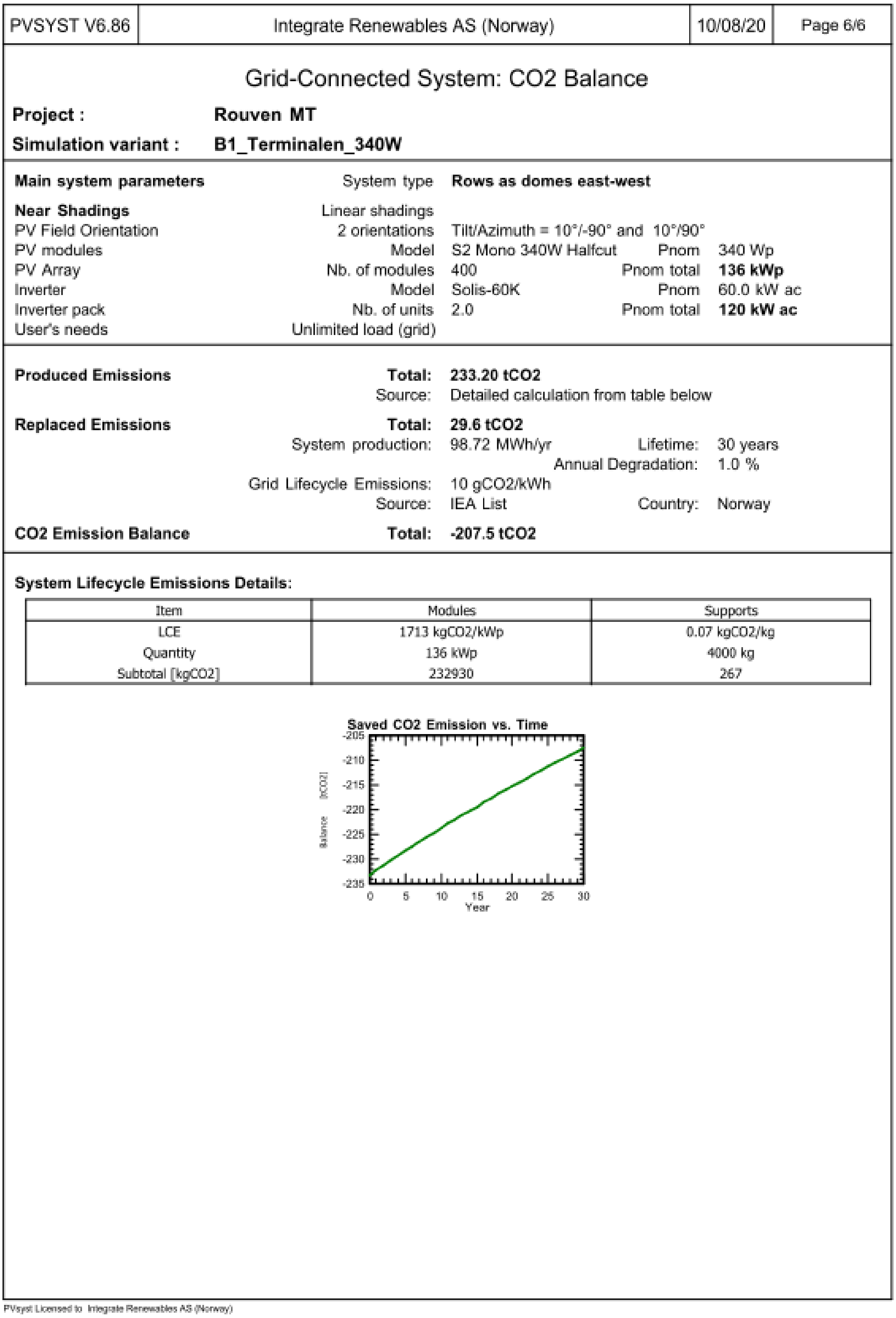

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Grid-Connected System: CO2 Balance

Project : **Rouven MT**

Simulation variant : **B1_Terminalen_340W**

Main system parameters	System type	**Rows as domes east-west**		
Near Shadings	Linear shadings			
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/-90° and 10°/90°		
PV modules	Model	S2 Mono 340W Halfcut	Pnom	340 Wp
PV Array	Nb. of modules	400	Pnom total	**136 kWp**
Inverter	Model	Solis-60K	Pnom	60.0 kW ac
Inverter pack	Nb. of units	2.0	Pnom total	**120 kW ac**
User's needs	Unlimited load (grid)			

Produced Emissions	**Total:**	**233.20 tCO2**		
	Source:	Detailed calculation from table below		
Replaced Emissions	**Total:**	**29.6 tCO2**		
	System production:	98.72 MWh/yr	Lifetime:	30 years
			Annual Degradation:	1.0 %
	Grid Lifecycle Emissions:	10 gCO2/kWh		
	Source:	IEA List	Country:	Norway
CO2 Emission Balance	**Total:**	**-207.5 tCO2**		

System Lifecycle Emissions Details:

Item	Modules	Supports
LCE	1713 kgCO2/kWp	0.07 kgCO2/kg
Quantity	136 kWp	4000 kg
Subtotal [kgCO2]	232930	267

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Link to all PVsyst and K2 reports:

https://drive.google.com/drive/folders/1mzYdHdlmWlQAfTDsB4_N8hvp3AFC3ziH?usp=sharing