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A techno-economic analysis on the replicability of smart grid solutions: Case study of holiday park 'De Krim' on Texel, island in the Netherlands

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Originality declaration

By this letter I declare that I have written this thesis completely by myself, and that I have used no other sources or resources than the ones mentioned.

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Executive Summary

The European Smart IsLand Energy Systems (SMILE) project demonstrates several smart grid technologies on three European islands with similar geographical characteristics but different markets, policies and regulations. This study investigated how smart grid technologies, demonstrated by the SMILE project, can be replicated on the island of Texel in the Netherlands and this way foster the market introduction of these smart grid technologies so they could be implemented anywhere in Europe where they have similar characteristics and challenges. Holiday park De Krim on Texel was used as a case study to study the replicability of these demonstrated smart grid technologies. De Krim expects an increase in their electricity demand in the next 30 years which will cause grid congestion issues. A solution is to upgrade the grid for €2 million euros. This study looks at an alternative solution. A smart grid solution.

This study identified that the four main key performance indicators that determine the replicability of smart grid technologies are the: technical, financial and economic, regulatory and administrative, and social dimensions. Due to a positive indication in the latter two dimensions this study focused on a techno-economic analysis of smart grid technologies. Combining solar panels and lithium-ion batteries were identified to be the most promising smart grid technologies for this case study. By using a minimum of 48 solar panels and approximately 50 kWh of lithium-ion storage capacity the expected increase in the electricity demand for holiday park De Krim in 2050 can be managed. It was calculated that there would be a shortage in the current electricity grid' capacity during the evening hours in the month of August for the coming 30 years. These were identified to be the peak consumption hours, which determined the maximum grid distribution capacity. A total investment of €7.470.134,92 is needed in the next 30 years when the grid would be upgraded. In contrary to installing a maximum of 669 panels and 50 kWh of storage capacity, only a total investment of €4.789.521,10 would be needed.

Smart grid technologies could be replicated on Texel by first engaging all the stakeholders that are involved in such a project. Then the technical issues should be identified, and a smart grid technology assessment should be carried out to identify the smart grid technologies that could solve these technical issues. Afterwards, these should be optimized in a technical model to fit the technical specifications and simulate reality. Then all the costs and benefits should be identified and all the possible financial solutions to cope with these costs. Finally, a regulatory and administrative analysis should be carried out to cope with all the legal issues related to the project.

To foster the market introduction of smart grid technologies, so they could be implemented anywhere in Europe, the technical, financial and economic, regulatory and administrative, and social dimensions need to be investigated. Active stakeholder participation by involving experts and representatives who are responsible for implementing the strategy is essential for a project's success. Technology is almost never the issue and with a viable business plan to finance the technological solution it will most likely not be an issue to implement the proposed technical solution. However, a project should start with the bottom-up and co-creation approach because hereby smart grid technologies will have a bigger chance to be successfully implemented. Without the public support a project is more likely to fail.

Index

Abbreviations and Acronyms

AMI	Advanced Metering Infrastructure
BCR	Benefit-Cost Ratio
BESS	Battery Energy Storage System
DSM	Demand Side Management
DR	Demand Response
DSO	Distribution System Operator
EMS	Energy Management System
EU	European Union
ESS	Exploitation Strategy Seminar
EV	Electric Vehicle
HP	Heat Pump
KER	Key Exploitable Results
KPI	Key Performance Indicator
kWh	Kilowatt-hour
NEC	New Energy Coalition
PCM	Phase Change Material
PV	PhotoVoltaic
RE	Renewable Energy
RES	Renewable Energy Sources
RVO	Rijksdienst voor Ondernemend Nederland
SMILE	Smart IsLand Energy Systems
TCO	Total Cost of Ownership
UAS	University of Applied Sciences
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
VVE	Owners Association
Wh	Watthour

1. Introduction

1.1. Background

The Smart IsLands Energy Systems (SMILE) project has received a €14 million funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 731249 [1]. The SMILE project grasps a very important aspect of the whole energy transition, namely the integration of smart grid technologies to cope with the fluctuations caused by the increase in energy demand and Renewable Energy Sources (RES), and thus the supply and demand within the energy system.

The SMILE project is demonstrating different smart grid technologies on three different European islands. These pilot islands have similar topographic characteristics but different policies, regulations, and energy markets. The pilot islands are Madeira in Portugal, Samsø in Denmark, and the Orkney Islands in the United Kingdom. What all three islands have in common is that they struggle with the frequency issues of the intermittency of renewables and the fluctuations of demand during high tourist seasons, which is common to several locations in Europe. Since the pilot islands have different characteristics, they will all have a different combination of technical solutions that best suit their specifications and infrastructure. The pilot islands are therefore a good representative of most of the energy markets in the EU and are expected to deliver maximum impact in terms of replicability. The overall goal of the SMILE project (2019) is to foster the market introduction of these smart grid technologies so they could be implemented anywhere in Europe where they have similar characteristics and challenges. The purpose of this study is to assess the replicability of the smart grid technologies demonstrated by the SMILE project and see if they could be replicated to solve the grid congestion problems on the island of Texel located in the Netherlands.

1.2. Smart Grids

Keeping global temperature rise well below 2 degrees Celsius, as targeted upon in Paris Agreement [2], necessitates the global energy system to go through an intense transformation, from a system depending highly on fossil fuel resources to the one that is fundamentally based on more efficient energy production from renewable sources. This global trend is called as energy transition and requires flexibility to be employed by all means in the current power system. Power system flexibility comes from more flexible generation and consumption of energy, stronger transmission and distribution systems and integrated storage technologies [3].

Due to the availability and environmentally friendly nature of renewables, as well as the application of smart grid in renewable energy, integration of renewables is viewed as precious [4], [5]. Nevertheless, the unstable characteristics of energy production from renewable sources like solar and wind into distribution grids perplexes the balancing of demand and supply, which in turn increases the risk of grid instabilities [6]. Many recent studies [7], [8], [9], [10] have assessed high penetrations of renewable generation and investigated methodologies to deal with the increase in net-load fluctuations and uncertainty which in the end highlight the reliability management of the electric grid. Traditionally, electricity has flowed one way, from a power station to a customer. With additional sources coming from alternative sources, electricity must enter the grid from multiple locations. Grid automation, two-way power flow and modern controls are needed to bring wind, solar and other alternative sources into the distribution grid and move it to its destinations. These emphasize the need for the development of smart grid technologies [11]. This study defines a smart grid as: "*A self-learning system, which uses various technologies to create a bidirectional communication system to find solutions to problems in the electricity system* *with the aim on reducing the work load and increasing the availability of sustainable, reliable, and safe electricity to all consumers*" [12].

The evolution of a smart grid will not occur overnight. Such a paradigm shift will require a step-by-step learning process over the coming years by testing smart grid technologies and business models to build confidence among various stakeholders and create a solid business case for the integration of a smart grid. There are several projects currently working on implementing and testing smart grid technologies. Some of these projects are being carried out on islands [1], [13].

1.3. Making smart islands

Approximately 15 million people live on Europe's 2.400 islands. A lot of these islands are small isolated systems. However, these islands have the potential to become the frontrunner on the energy transition by implementing innovative solutions and adopting new technologies, such as the smart grid technologies. Islands often have strong communities. Community involvement is very important for a paradigm shift like an energy transition and thus the implementation of smart grid technologies. The integration of a smart grid requires community approval and involvement since it not only requires infrastructural changes, but also environmental and behavioural changes. Experimental studies of smart grid demonstrations are being held on islands because they act as real-life with laboratories, a test bed where smart grid solutions can be tested on a small scale the aim to implement them on a larger scale in cities and countries throughout the world [14].

At the Paris Agreement of 2015 the EU has committed to achieve its climate objectives and dedicated 20% of its entire budget from 2014 till 2020 to climate-related actions [15]. The EU's commitments to the Paris Agreement is called the 'Clean Energy for all Europeans Package'. An initiative was developed from this package named the 'Clean Energy for EU Islands'. This Clean Energy for EU Islands provides a long-term framework to help islands in the EU to produce its own sustainable energy at low costs. This initiative was launched in 2017 in Malta and signed by the European Commission and 14 EU member states. The island communities are the ideal candidates for energy transition demonstration activities that require societal engagement and active residents' commitment. Such island communities can be more easily engaged (compared to mainland) in the real-life testing of solutions aiming to solve energy related challenges impacting life on the island and also the speed of the transition itself. In many cases the grid connection is either non-existent or limited to a certain level. Therefore, the EU has developed a Research and Innovation Programme called as Horizon 2020 and Clean Energy for EU Islands to stimulate research and innovation throughout Europe and make innovations more extensible for all European citizens, especially for those who live on islands [16].

1.3.1. Texel, the Netherlands

Texel is an island located in the north-west and is 463.2 km-squared and therefore the biggest island in the Netherlands. The island has approximately 13.500 inhabitants. Around 80% of the total income comes from tourism and Texel has the capacity to house 45.000 tourists. Since the tourist accommodations have become more luxurious (meaning: less campsites more bungalows, houses, hotels e.g.) the tourist season has become longer and lasts from February till November, the island has reached its tourist capacity. The energy consumption of the island is very inconsistent. This results not only in significant daily fluctuations, but also significant seasonal variations as tourism has its peaks in the summer. This has a negative effect on the electricity grid such as congestions and grid imbalances [17]. The energy consumption per capita on Texel is circa 10% higher compared to the rest of the Netherlands and the RE generation per capita is almost 50% less compared to the rest of the Netherlands [18]. Moreover, in 2009 around 12% of the total electricity consumption on Texel came from tourist residencies and 41% came from electricity [19].

Texel has multiple sub-goals which could help them to achieve their main goal of becoming a self-supporting and sustainable island. These goals are [17]:

- ✓ Producing sustainable energy
- ✓ Sales distribution of sustainable energy
- ✓ Promoting energy reduction
- ✓ Cooperating with likeminded organisations
- ✓ Supporting Texel' ambitions to the use of sustainable energy

Texel has a relatively high potential for RE generation. It is estimated that the RE generation potential on Texel is circa 645 TJ per year [19]. A RE generation potential does not mean that this will be generated in the future. It is just an indication of what the possibilities are for the island of Texel regarding the generation of RE. Knowing their RE generation potential, Texel has established a roadmap towards their future energy mix and helps them to achieve their goal of becoming self-supporting. Between 2015 and 2050 it is expected that the future energy mix of Texel will increase and consist mostly out of solar power (444 TJ), wind power (220 TJ), local heat (460 TJ) and imported hydrogen(95 TJ) [17].

The Duurzame Energie Alliantie is a collaboration of people from Texel that together aim for an energy self-supporting Texel by 2040. They learn from their own mistakes in previous projects and those of others and try to look forward. They are driven by three main factors: collaboration, climate change and the development of Texel as a knowledge economy. The Duurzame Energie Alliantie believes that collaboration is very important when it comes to an energy transition goal like Texel'. They looked at the Danish island Samsø who has become one of the frontrunners when it comes to the energy transition on islands. Samsø has done this by collaborating between, inhabitants, companies and the governments. They have concerned all the stakeholders from an early stage by letting them think along, co-decide and by making them financially part of the entire plan, becoming energy self-supporting. However, Samsø has two main advantages. First, Samsø has less inhabitants than Texel so it is easier to collaborate between stakeholders and, secondly, Samsø does not have a well-developed gas infrastructure, which made it easier for them to look for other heat system alternatives, in contrast to Texel, who has a well-organized gas infrastructure which makes it rather difficult to motivate stakeholders to look at other heat alternatives. Nevertheless, Samsø and Texel have a similar island culture, in terms of a close island community, which makes the islands rather interesting for demonstrating energy transition projects in the first place. Samsø uses the bottom-up co-creation approach which could possibly also work for Texel. However, Samsø is circa four times smaller as regards to size and inhabitants, which might make this approach rather difficult. A bottom-up and co-creation approach is focused on two main subjects:

- Starting small in all openness and concern all stakeholders from the start (e.g. companies, government, inhabitants, experts, scientists, entrepreneurs and system operators)
- Use the (gained) knowledge in a way that benefits the entire community and economy

The first attempt of making Texel energy self-supporting by 2020 failed due to lack of stakeholder engagement and participation [20]. Only 3% of Texel' energy demand is currently generated by RE. Projects are often managed with the top-down approach where the most powerful stakeholders also have the most influence. For some stakeholders on Texel it is unclear or even unfair who is paying for projects, that should help Texel becoming self-supporting, and who is profiting from it. Value must be created for all the stakeholder to increase their interest and participation in the implementation of innovative technological solutions. Therefore, organisations like TexelEnergie and the Duurzame Energie Alliantie are now focusing on increasing the stakeholder engagement and, like Samsø, use the bottom-up and co-creation approach. Often sustainability projects come from governments or municipalities, but this is more so focused on the top-down approach, which are not always the most effective solution.

1.4. Replicability

To increase the impact of research results and foster the market introduction of piloted innovations, such as the smart grid technologies demonstrated by the SMILE project and create smart cities worldwide, a replication investigation needs to be carried out to determine the Key Performance Indicators (KPI) that hinder or encourage the replicability of smart grid technologies. The Smart Cities Information System (SCIS) project, funded by the EU, is a knowledge platform to exchange data, experience, knowledge and to collaborate on the creation of smart cities, by replicating smart grid technologies. The creation of smart cities throughout the world is the overall goal of smart grid related projects. SCIS outlines four main dimensions that need to be considered when approaching a replication project: technical, financial and economic, regulatory and administrative, and social. Stakeholder participation is identified by experts to be the most important factor that determines the implementation and smart cities and communities' solutions (SCC) [21]. Active stakeholder participation by involving experts and representatives who are responsible for implementing the strategy is essential for a project's success.

Replicability in this study refers to: "*Potential implementation of the technological solutions resulting from the SMILE project' pilot islands to holiday park De Krim under the consideration of its system boundaries*" [21] (2019, p.8). The European Commission' report on replication and scale-up of innovation in Europe is focused on cities, which is a relative large-scale project compared to the pilot projects of the SMILE project and is therefore related to 'scalability'. Holiday park De Krim exist out of 500 residencies which makes it a relatively small-scale project. Therefore, since De Krim is a relatively small-scale project, this study will only focus on the replicability and not on the scalability of smart grid technologies.

1.5. Case study: implementing smart grid technologies at holiday park De Krim

This study will use the case study of holiday park De Krim to assess the replicability of smart grid technologies. Holiday park 'De Krim Texel' is constructed in 1969 and is the biggest park on the island of Texel. It has approximately 500 tourist residencies with 13.000 beds and covers approximately 30% of the market share on Texel [22]. Around 70% of the residencies are privately owned and are collectively connected to the grid and therefore they owner's association (VVE) act as a private network operator [20]. This makes it rather difficult for De Krim to participate in the energy transition, since every change in the electricity production or consumption affects the Krim's entire electricity grid. Because of the peak fluctuations during the high seasons caused by the high electricity demand and consequently the low demand during low season, the grid struggles with congestion problems. Installing electrical appliances, solar panels or charging stations for electrical vehicles are expected to cause even more peak loads and load fluctuations on the electricity grid [23]. A solution could be to connect each residency separately to the electricity grid, but this comes with rather high costs. 'Upgrading' the grid to an appropriate safe level will cost approximately €2 million euros [20]. Therefore, there is a strong demand for other possible, smart solutions that might reduce the pressure on the electricity grid and tackle congestion problems. The idea is that such solutions will be of a long-term nature and would still be applicable in 30 years. The tourist residency limit on Texel reaches its maximum capacity. However, the residencies become more luxurious and may include, jacuzzies, sauna's, tanning beds and indoor- outdoor swimming pools. Due to the energy transition it is expected that in the coming years more tourist will visit De Krim with electric vehicles and the demand for charging points will increase. Unfortunately, the current electricity grid is not capable of handling electric vehicles caused by the increase in electricity consumption. Both the increase in electricity demand and the limited electricity grid capacity, is expected to lead to further grid congestion problems. This combined with the sustainable development goals of Europe, the Netherlands and the municipality of Texel, reducing CO_2 emissions and increasing the production of renewable energy [17], drives a strong need for a long-term smart grid solution.

The socio-cultural environment at holiday park De Krim exists out of a relatively small group of residential owners (circa 450) who together form the VvE and form a strong community. The VvE owns all the facilities at the park (e.g. shops, restaurant), which makes a collective consensus between the relatively easy. The key stakeholders have an interest in this project since they are forced to look for a possible solution that solves their grid issues. The residential owners have an economic interest in this project because of their mutual problem, which needs to be addressed otherwise De Krim will cope with grid instabilities that can lead to a decrease in consumers. An increase in consumer expenditures will support the economic growth on the island and thus provides economic benefits for various businesses on Texel, including De Krim. It is crucial to create some sort of value for all the stakeholders that are included in this project to succeed, otherwise the project might fail. Stakeholder engagement is expected to be relatively easier at De Krim compared to the island of Texel because there is only one key stakeholder in De Krim project, with one mutual problem, the residential owners. Figure 1 illustrates the stakeholders that are involved in this case study.

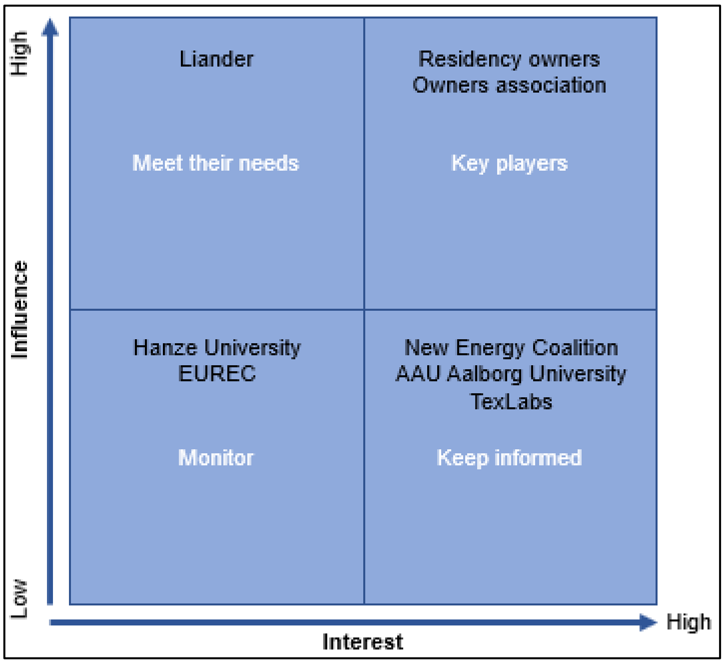

Figure 1. Stakeholder Map of holiday park De Krim.

The province of Noord-Holland funds (innovative) sustainability projects in the building environment such as the De Krim project. This suggests a regional-political incentive for sustainability initiatives [24]. On Texel the turn-out during the municipal elections was 25.7% less compared to the national elections, which could mean that the community on Texel is less regionally oriented than someone might expect from an island community. The municipality of Texel, the energy supplier, the DSO, and water supply company on the island only have an interest in the connection with the holiday park De Krim itself. From then on it is the VvE' responsibility [20]. Only the VvE hast to accept the proposed smart grid solution for it to be implemented. However, it is needless to say that the national and local laws and regulations regarding the implementation of the concerned smart grid technologies must be met.

For a possible increase in the renewable electricity consumption and generation without upgrading the current electricity grid an electricity storage system and an electricity generation system are required. One of the most advanced and commonly used electricity generation systems for the building environment is a photovoltaic system. However, Texel has a lower RE generation by photovoltaic systems in the building environment compared to the national average, even though Texel has the highest amount of sun hours in the Netherlands [25]. Therefore, there is still a lot to gain from a RE generation perspective. Moreover, a wind turbine could also generate the required RE for De Krim. Texel is located in a relatively high-wind area after all [26]. Although, the implementation of a wind turbine comes with several societal challenges.

Several studies have shown economic benefits for the consumers, producers and the DSO by implementing smart grid solutions [27], [28]. Energy consumers have numerous economically benefits from Demand Side Management (DSM) techniques such as a decrease in energy bills, increase in long-term jobs and an increase in the competitiveness of local enterprises for instance. Concluding, the ratio between the costs and benefits of a smart grid makes them financial interesting for all stakeholders.

The unemployment ratio on Texel is 0.8% lower compared to the rest of the Netherlands but Texel' population has 0.4% less income to spend [29]. Moreover, the Dutch Central Bureau for Statistics (CBS) stated that there is an economic growth of 2.0% on a yearly basis in 2019 and the unemployment levels have never been this low since decades [30]. However, the economic growth will decrease to 1.4% in 2020 [31].Several sources even indicate that there are signs for a possible recession caused by several economic issues such as the Trade War between China and the US and Brexit [32], [33]. Even though the Dutch economy is currently growing, a possible recession could affect the Dutch economy and therefore the economy on Texel, including the stakeholders engaged in the project at De Krim, which could have a negative effect on the financial and economic environment of such a project.

1.6. Conceptual model and research approach

The replicability of smart grid technologies is determined by the technical, financial and economic, regulatory and administrative, and social dimensions [21]. The previous preliminary investigation suggests that the current societal and regulatory and administrative, also known as the political-legal factors, somewhat show positive indications, such as stakeholder engagement strategies, for the deployment of smart grid technologies at holiday park De Krim. Therefore, it is assumed that the KPI's for the replication of smart grid technologies are mostly related to technological and financial-economic aspects, due to the current global economic tensions and lack of created value for the various stakeholders in Texel' previous projects. Therefore, this study is focusing on the technical and financial-economic dimensions only. Figure 2 illustrates the system boundaries of this study.

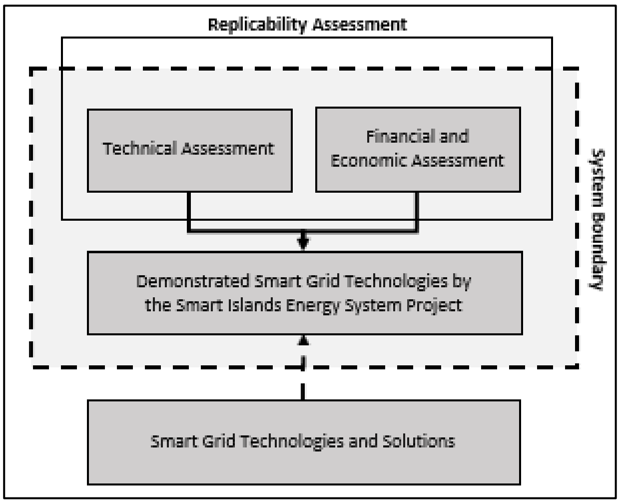

Figure 2. Conceptual framework

1.7. Relevancy and Research Questions

De Krim Texel was selected as a case study to assess the replicability of smart grid technologies that are developed within SMILE project. The purpose of this case study is to assess if and how smart grid technologies can be replicated to solve a growing number of grid issues related to the increased energy demand and intermittency of renewable energy sources. The proposed solution for De Krim should also form a viable business case. The overall goal is to identify which characteristics determine the replicability of smart grid technologies so that they can be implemented in other areas and solve similar grid related challenges.

The main research question that this study will answer is formulated as followed: "*How could smart grid technologies, which are demonstrated by the SMILE project, be replicated on Texel?"*

The question has been divided in four different sub-questions (SQ). Each question will focus on a different topic that will help to answer the main research question. The following sub-questions are established:

1. *"Which key performance indicators determine the replicability of the smart grid technologies"?*
2. *"What smart grid technologies and solutions can solve the challenges faced at holiday park De Krim Texel"?*
3. *"How could these technologies be implemented at holiday park De Krim Texel"?*
4. *"How viable are these smart grid solutions compared to the alternative of an electricity grid upgrade"?*

2. Methodology

2.1. Research Design

Several research methodologies were carried out in order to answer the main research question of this study. Table 1 discusses which methodologies will give answer to the which sub-question.

Table 1. Research Design

	Methodology	SQ
Phase 1 – Orientation	Expert Interviews	1-2
Phase 2 – Researching	Smart Grid Technology Assessment	2-3
	Technical Modelling	3
	Cost-Benefit Analysis	3-4
	Business Canvas Model	3-4
Phase 3 – Analysing and Evaluation	Analysing Results	1-4
	Conclusions and Discussion	1-4

2.2. Expert interviews

Several experts were interviewed to gain an understanding on the technical and financial dimensions regarding the implementation of smart grid technologies and gathering the necessary data for carrying out the research methodologies.

Semi-structured interviews were used during the Smart Grid Technology Assessment. The following exerts were approached: J. Kuiken (TexelEnergie), P. Lijklema (TexLabs), J. Jantzen (Samsø), I. Andrade and M. Vieira (Madeira), S. Bee (Route Monkey), M. Swierczynski and B. Böwadt Iversen (Lithium Balance A/S).

Unstructured/open discussions were held during the Technical Modelling methodology. The following experts were approached: F. Cansu Ertem-Kappler, M. Renz, M. van Schot, and M. de la Vieter (project managers at NEC).

Semi-structured interviews and unstructured/open discussions were used during the financial-economic and business modelling methodology. The following expert was approached: M. de la Vieter (business developer and project manager at the NEC).

2.3. Smart Grid Technology Assessment

Several technology requirements of holiday park De Krim were established in the orientation phase of this study (table 2). The requirements have been rated by level of importance after discussing them with various stakeholders of holiday park De Krim. These technology requirements are necessities that should help De Krim to solve their grid congestion problems. They were established by interviewing several experts regarding the smart grid technologies and previous related projects. They function as the starting point of the Smart Grid Technology Assessment methodology.

Table 2. The requirements for a smart grid solution for holiday park De Krim are summarized below and rated by the level of importance from 1 (slightly important) to 5 (highly important).

Nr.	Requirements of holiday park De Krim	Weight
1	Increasing the electricity grids capacity to cope with an increase in electricity consumption due to an expected increase in electrical appliances (e.g. electric vehicles, electric heating, electric cooking).	5
2	Increasing the electricity grids capacity to cope with an increase in electricity generation by renewable energy sources (e.g. photovoltaic panels and wind turbines).	5
3	The smart grid solution(s) should, preferably, be lower in costs than upgrading the grid to an appropriate safe level, which cost approximately €2 million euros. However, the costs are NOT leading.	3

4	The smart grid solution(s) will be of a long-term nature and must still be applicable after 30 years.	5

The requirements in table 2 were discussed with various experts (section 2.2.) to identify the smart grid technologies that could solve the challenges faced at De Krim. The Technology Readiness Level (TRL) of the proposed smart grid technologies were established by the island demonstrators within the SMILE project. The results of the Smart Grid Technology Assessment were discussed and verified with various stakeholders and experts before being accepted for further research.

2.4. Technical Modelling

The smart grid solutions that were identified by the Smart Grid Technology Assessment were dimensioned to fit the technical specifications (e.g. consumption and generation patterns) of De Krim. Within this study modelling is refers to: "*Using existing systems and models to imitate reality to make future predictions*". The technical modelling of the smart grid solutions helped to identify the necessary equipment and capacities which are needed to cope with the expected increase in the electricity demand and balance the future electricity grid. The project lifetime is 30 years, starting in 2020 and ending in 2050. Technical modelling experts were contacted when necessary to verify the technical model' validity and reliability.

The technical model is performed by using Microsoft Office 365 Excel. The data regarding the current electricity demand was provided by Jord Kuiken, energy counsellor. The demand patterns were provided on a 15-minute basis for the last six years. Due to time constrains and limited resources this data is calculated towards an average twenty-four-hour demand pattern for each month. The expected electricity demand in 2050 was calculated by de Gasunie and published in '*Gasunie, verkenning 2050, discussiestuk'* [34]. This study is focused on a project lifetime of 30 years. Therefore, a linear approach is used for the increase in electricity demand between 2020 and 2050. The data regarding the smart grid technologies were provided by the technology provider Lithium Balance A/S an AEG.

To identify the most optimal smart grid solution for this case study and fit the requirements of De Krim (table 4) the technical model is built around five scenarios. These five scenarios are explained further below:

A. The first scenario (A) is the <u>grid scenario</u>. This scenario is based on the alternative grid solution. Upgrading the current electricity grid to cover to cover the future increase of electricity demand.
B. The second scenario (B) is the <u>smart grid scenario</u>. This scenario is based on a smart grid solution by using solar panels and lithium-ion batteries to cover the grid capacity shortage due to the future increase of electricity demand.
C. The third scenario (C) is the <u>cheapest scenario</u>. This scenario is based on identifying the cheapest solution by using smart grid technologies to cover the future increase of electricity demand.
D. The fourth scenario (D) is the <u>greenest scenario</u>. This scenario is based on identifying the solution with the lowest carbon footprint by using either a grid upgrade, smart grid technologies or both to cover the future increase of electricity demand.
E. The fifth scenario (E) is the <u>battery-grid scenario</u>. This scenario is based on identifying the required technical specifications by using lithium-ion batteries and electricity from the grid t to cover the future increase of electricity demand.

2.5. Financial-Economic Assessment and Business Modelling

Business modelling techniques were used to describe how the implementation of the smart grid solutions create, deliver and capture economic value for all the engaged stakeholders. This business model will assess the economic viability of the project and exists out of: financial costs, financial risks, unforeseen costs and financial solutions. Furthermore, the business model will provide and accurate estimation of the projects total costs to determine the profitability of the investment. The financial costs contain the capital expenditures (CAPEX) and operational expenditures (OPEX). These costs will be analysed together with the project' benefits in a cost-benefit analysis (CBA). Financial-economic and business modelling experts were approached to discuss and verify the financial-economic aspects and business modelling tools that were used (table 4).

The financial model is performed by using Microsoft Office 365. The data related to the CAPEX and OPEX is gathered from the technology providers (AEG and Lithium Balance A/S), and experts on economics, business models, and subsidies. Finally, a sensitivity analysis is performed based on scenario B.

2.5.1. Cost-Benefit Analysis

A CBA is carried out to address all the financial costs and compare them to the benefits of the smart grid solutions. CBA experts were approached (table 4) to discuss and verify the CBA that was carried out during this study. The steps are supported by the CBA guidelines of the European Union [35]. Benefits that cannot be expressed in financial capita are also addressed and marked as 'token entry'. The costs were determined by the technology providers, experts and literature review.

2.5.2. Business Canvas Model

A Business Canvas Model (BCM) is used to create a business strategy. The nine steps provided within the BCM help to identify the; key partners, key activities, key resources, value proposition, costumer relationship, channels of communication, costumer segmentation, cost structure and revenue streams. The BCM is developed for the scenario with highest Benefit-Cost Ratio (BCR). This is assumed to be the scenario which is most likely to be implemented due to its relatively high change of success. Figure 3 shows a flow chart of the methodologies used within this study.

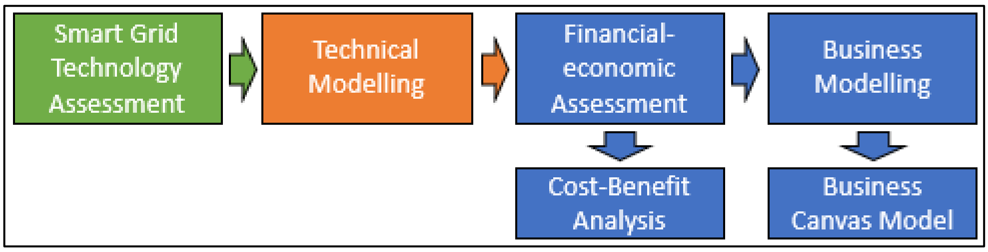

Figure 3. Flow Chart methodologies

3. Results

3.1. Smart Grid Technology Assessment

The Smart Grid Technology Assessment results are reviewed in this section. The results are divided in two sections. First is addressed the proposed smart grid technologies. Secondly, the TRL.

3.1.1. Proposed Smart Grid Solutions

The smart grid solution that has been recommended by the island demonstrators of the SMILE project is the XOLTA Energy Storage System manufactured by Lithium Balance A/S in combination with solar panels. By using these two systems extra electricity can be generated, stored, and consumed at another moment. Such a system makes it possible to increase the demand for electricity without putting more load on the current electricity grid.

The XOLTA Energy Storage System is a lithium-ion battery that is manufactured by Lithium Balance A/S and is developed to be safer than alternative batteries. They are suitable for households whom produce electricity by using PV panels but are not able to use this electricity. They have increased the energy efficiency by reducing the inverter losses from 30% to 3%. By forecasting energy generation and consumption and using a cloud EMS the XOLTA battery can increase energy savings by 15%. The XOLTA battery controller is also able to interface with other energy assets such as heat pumps and EV chargers. Most of the risk of this BESS are related to the market since there are many other competitors currently working on household batteries to store renewable electricity. Table 3 discusses the technical specifications of the XOLTA energy storage system.

Table 3. Technical specifications of the XOLTA Energy Storage System

	XOLTA Energy Storage Sytem [36]	Unit
Capacity (per rack)	79000	Wh
Charge efficiency	94	Percentage
Discharge efficiency	94	Percentage
Price in euro's	€570 – €600/kWh	Euro's/kWh
Technical/economical lifetime	15	Years

De Krim wants to increase their renewable electricity production. Therefore, photovoltaic (PV) panels were integrated in the technical model. This study has used the AEG model AS-P602 260 Wp (watt-peak). These are the best price-quality PV-panels currently available (table 4).

Table 4. Comparison of different PV-panels that are currently available.

	AEG AS-P602 260 [37]	Boviet BVM6610P-255 [38]	Conergy PowerPlus 250P [39]
Capacity	260WP	255WP	250WP
Efficiency	95%	-	95%
Price in euros	142.60	185,16	192,53
Dimensions (m)	1,485*0,981	1,485*0,981	1,485*0,981

For more information about the proposed smart grid solutions please see appendix 7.1.

3.1.2. Technology Readiness Level

A technical assessment has been performed by the three island demonstrators and has led to the Technology Readiness Level (TRL) [40] of the XOLTA energy storage system. Table 5 illustrates the TRL that was given by the island demonstrators.

Table 5. Technology Readiness Level of the XOLTA lithium-ion battery manufactured by Lithium Balance A/S.

TRL	Definition [40]	Technology	Island
1	Basic principles observed		
2	Technology concept formulated	Lithium Balance controller	Samsø
3	Experimental proof of concept		
4	Technology validated in lab		
5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)	Lithium Balance battery & cloud	Orkney
6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)		
7	System prototype demonstration in operational environment	Lithium Balance battery	Samsø
8	System complete and qualified		
9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)	Lithium Balance battery & controller	Madeira

3.2. Technical Modelling

The previous Smart Grid Technology Assessment has determined that the most feasible smart grid technology for holiday park De Krim is the 79kWh/stack XOLTA Energy Storage System manufactured by Lithium Balance A/S. To increase the renewable energy production and maximize the potential use of the proposed storage system, the AEG model AS-P602 solar panels were used. Both the storage system and the solar panels have been implemented in a technical model. The input parameters are shown in appendix 7.2.

Figure 4 illustrated the Energy Flow Analysis of all the scenarios. During the months when there is leftover grid capacity the electricity demand is first supplied by solar panels (A), then by the grid (B), leftover electricity from the solar panels is stored (B) in the battery and consumed when needed (C). In the months when there is no leftover grid capacity the electricity demand is first supplied by the grid (A) and the electricity from solar panels is stored (A) until the storage is full and consumed (B) during the moments when there is no leftover grid capacity (B).

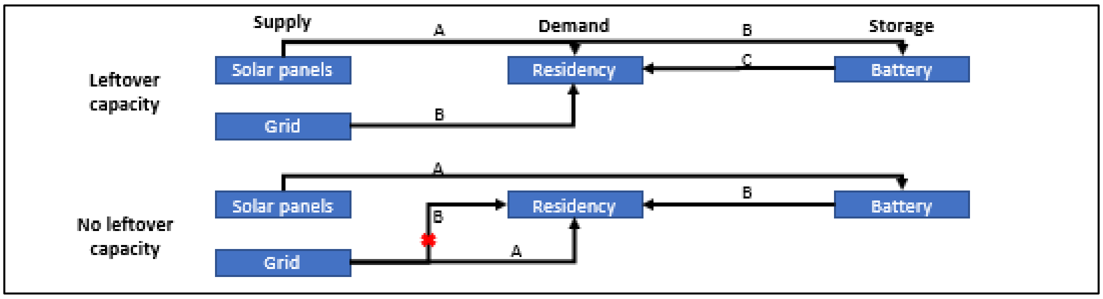

Figure 4. Energy Flow Analysis (EFA) of all the scenarios.

3.2.1. Scenario B – mid case scenario

Scenario B is based on a smart grid solution by using solar panels and lithium-ion batteries to cover the grid capacity shortage due to the future increase of electricity demand.

Electricity demand

De Krim has 500 tourist residencies. In 2018 De Krim consumed 672.865 kWh [20]. To cover the increase in electricity demand between 2020 and 2050 the two proposed smart grid solutions were used. Extra electricity is generated by using solar panels and electricity is stored by using batteries. The data on the electricity demand of 2018 was used as the starting point of the project in 2020.

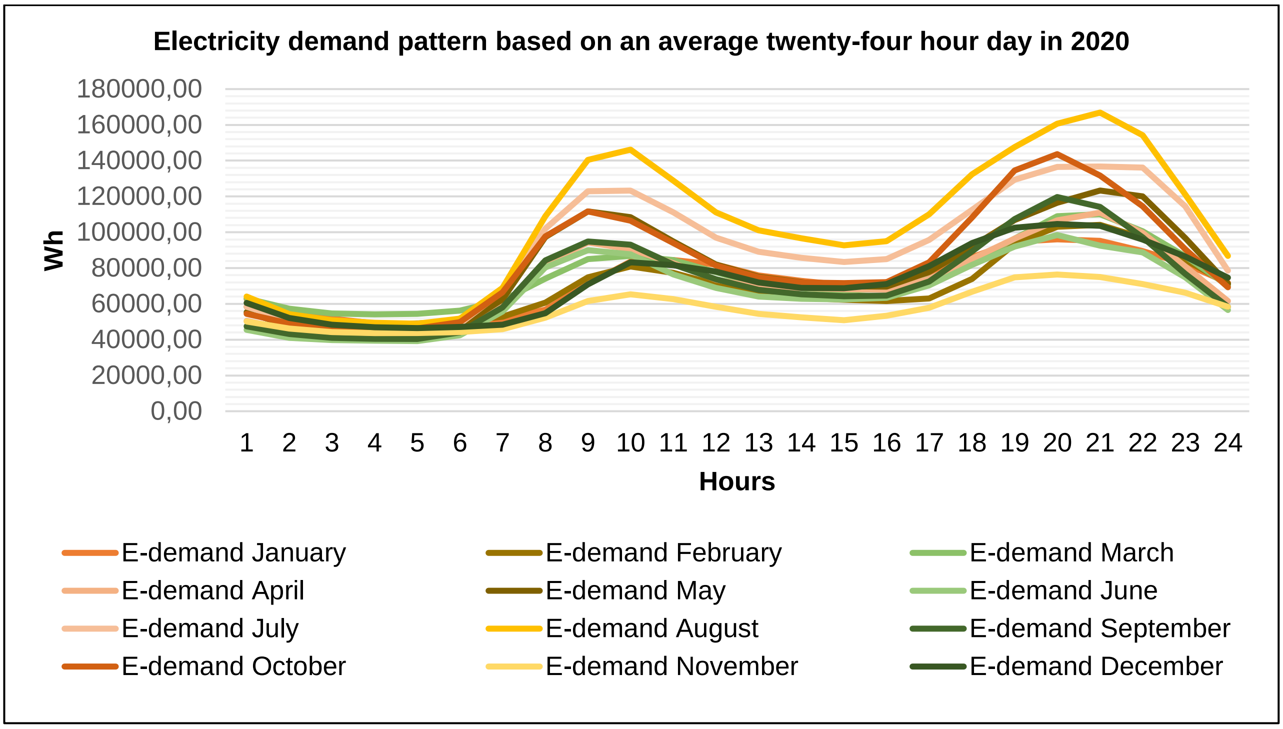

Figure 5. Electricity demand pattern in 2020 over a twenty-four-hour period for each month.

Figure 5 illustrates the 2020 electricity demand pattern of holiday park De Krim, which is being distributed by the electricity grid. The limited grid capacity is determined by the highest peak demand hour in 2020, which is approximately 167.000 Wh at 21:00 in August. When the electricity demand on an average November evening at 21:00, which is approximately 75.000 Wh, increases with 13% it will not come near the electricity demand at the same hour on an August evening. Therefore, this will not cause any grid congestion problems. 21:00 on an average August evening has the highest demand of all the hours in a year. If the electricity demand would increase with 13%, this hour would cause the expected grid congestion problems first.

Figure 6 illustrates the yearly increase in electricity demand between 2020 and 2050 when the 2020 electricity demand in 2050 has increased with 13%. A linear approach was used between the given data on 2020 and the expected demand in 2050. The total electricity demand between 2020 and 2050 is 22.214.648 kWh.

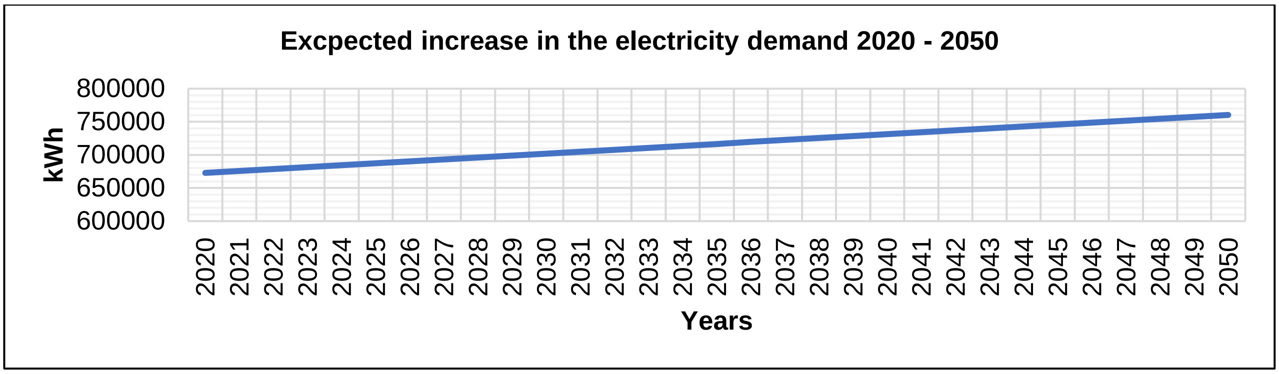

Figure 6. Expected increase in electricity demand between 2020 and 2050 based on a total increase of 13%.

Figure 7 illustrates the electricity demand based on an average twenty-four-hour day in 2050. The electricity demand in 2050 is based on an increase of 13% compared to the electricity demand in 2020 (figure 6).

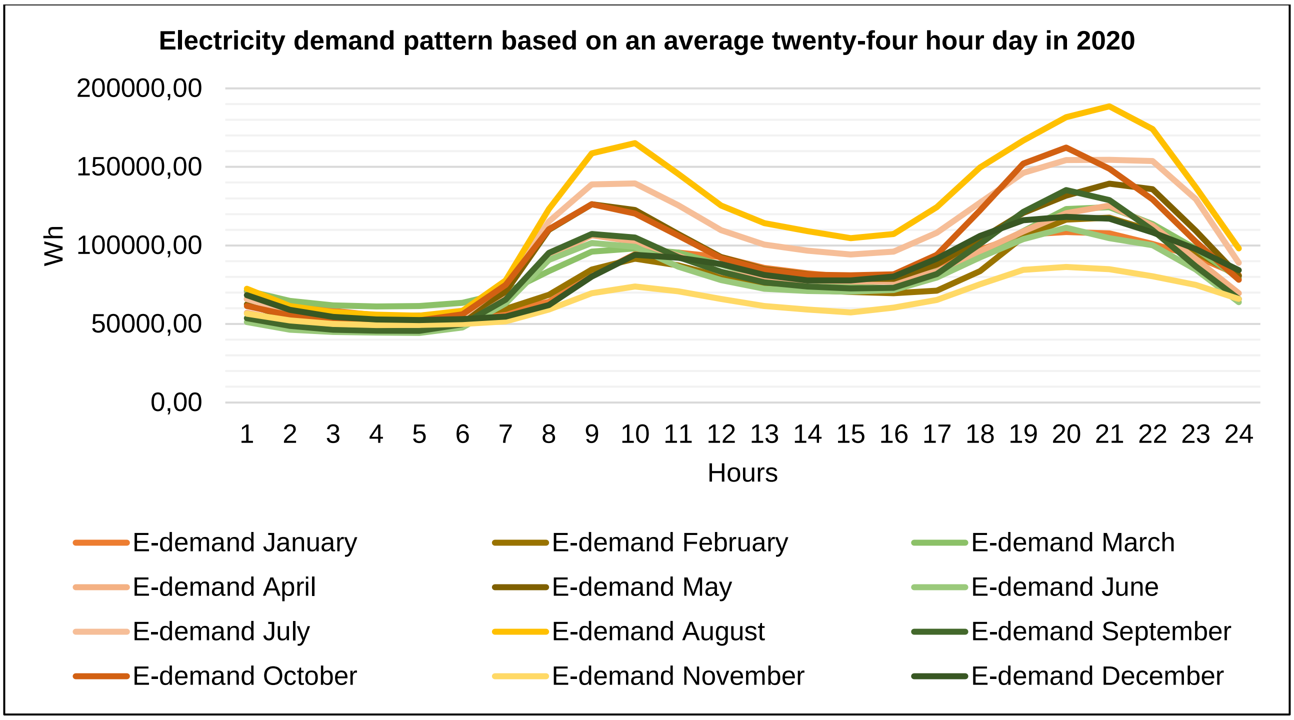

Figure 7. Electricity demand pattern in 2050 based on an average twenty-four-hour day in 2050.

Formula

<u>Calculating the electricity demand in 2050. Formula example based on electricity demand at 21:00 in August (figure 8).</u>

$$166877{,}42\ Wh \times (1 + 13\%) = 188571{,}48\ Wh$$

Table 6 illustrates the bottlenecks in 2050 when the current electricity demand illustrated in figure 5 increases with 13%. In 2050 the current electricity grid will not be able to fulfil the electricity demand of an average August evening between 19:00 and 22:00. There is a total shortage of 43.712 Wh. To cover the electricity shortage in August the total of 43.712 Wh needs to be generated by PV panels during the day and stored in batteries until the evening, when there is no solar irradiance, and no leftover grid capacity.

Formula

<u>Calculating the electricity grid capacity shortage in 2050. Formula based on table 9 at the hours 19:00 till 22:00 in August.</u>

$$5\ Wh + 14.717\ Wh + 21.694\ Wh + 7.296\ Wh = 43.712\ Wh$$

Formula

<u>Calculating the leftover grid capacity per hour, per month in 2050. Formula example based on electricity demand at 21:00 in August (figure 7).</u>

$$188.571{,}48\ Wh\ (demand\ at\ 21{:}00\ in\ August\ 2050) - 166.877{,}41\ Wh\ (demand\ at\ 21{:}00\ in\ August\ 2020) \approx 21.694\ Wh$$

Table 6. Leftover grid capacity in 2050 after a total increase of 13% in 2050 compared to 2020. Leftover grid capacity is marked green and grid capacity shortage is marked red.

Hour	January	February	March	April	May	June	July	August	September	October	November	December
1	-96067	-100973	-95746	-109765	-104429	-115524	-100944	-94477	-113264	-105413	-110319	-98421
2	-103867	-108679	-102088	-115211	-112936	-120562	-109335	-105493	-118076	-111420	-114671	-107899
3	-108453	-111311	-105070	-116640	-116195	-121918	-111223	-109349	-120518	-113264	-116829	-112339
4	-111347	-112010	-105704	-117216	-116924	-122312	-113658	-111019	-121094	-114591	-117551	-113906
5	-112105	-111500	-105456	-116793	-116611	-122581	-114533	-111580	-121233	-114591	-117420	-114387
6	-111274	-110224	-103444	-113330	-113454	-118987	-111675	-108402	-117121	-110647	-116902	-113724
7	-108540	-107177	-96941	-100484	-96249	-103882	-91204	-89097	-101279	-91904	-115167	-112178
8	-102693	-98217	-83228	-74239	-56866	-76149	-51610	-43758	-71578	-56538	-107775	-104910
9	-86567	-82295	-70798	-60359	-40682	-65243	-28055	-8167	-59637	-40616	-97379	-86749
10	-72373	-75377	-68757	-64529	-44327	-67780	-27494	-1722	-61795	-46587	-93034	-72854
11	-71389	-79481	-71338	-73525	-59659	-80465	-41221	-21348	-74341	-60672	-96132	-74720
12	-74327	-86764	-79189	-83833	-74327	-88958	-57187	-41389	-83600	-74946	-100929	-78767
13	-81085	-93274	-86684	-88754	-81931	-94419	-66227	-52602	-90300	-82390	-105413	-85576
14	-84657	-95206	-89214	-89097	-85350	-95884	-70084	-57727	-93019	-85474	-107658	-89104
15	-87085	-96446	-90781	-89746	-88076	-96300	-72541	-62181	-94310	-85918	-109437	-89192
16	-86516	-97262	-89447	-90037	-88105	-95184	-70820	-59491	-93763	-85284	-106499	-86655
17	-80611	-95724	-83228	-83396	-78869	-87296	-58755	-42446	-84985	-72912	-101578	-75260
18	-69661	-83279	-72679	-70521	-62976	-74516	-39690	-17178	-65972	-44531	-91510	-60803
19	-59979	-61408	-57851	-57945	-46172	-62859	-20663	5	-45486	-14860	-82361	-50925
20	-58332	-50371	-43758	-46383	-35229	-55605	-12541	14717	-31627	-4551	-80553	-48658
21	-59243	-49190	-42497	-41462	-27523	-62254	-12352	21694	-37955	-18038	-82084	-49831
22	-65855	-57581	-53272	-54271	-31153	-66621	-13066	7296	-57151	-37562	-86509	-58558
23	-73904	-71279	-69012	-75501	-57486	-82251	-37474	-29914	-80101	-64492	-92042	-69158
24	-85678	-86319	-87632	-97262	-86378	-102912	-78016	-68830	-100936	-88696	-101002	-82623

Electricity battery

The battery used in this study is the XOLTA energy storage system manufactured by Lithium Balance A/S. Each stack has a total storage capacity of 79.000 Wh. Energy is lost during the charging and discharging of the battery. The XOLTA battery has a charging efficiency of 94% and a discharging efficiency of 94%. More electricity needs to be generated than stated in table 6 due to these loses. The storage capacity needed is determined by electricity that needs to be generated plus the losses during charging and discharging of the battery.

Formula

<u>Calculating the necessary storage capacity. Formula based on electricity grid capacity shortage of table 9.</u>

$$43.712\ Wh\ \div 94\% \div 94\% = 49.471\ Wh$$

Electricity supply

The increase in the electricity demand between 19:00 and 22:00 in August is directly supplied by the installed PV panels, when possible, and by the installed battery. As illustrated in figure 8, there is a total solar irradiance of 4424 Wh/m2 on an average August day. To cover the demand between 19:00 and 22:00 on an August evening (table 6) a total of 49.471 Wh needs to be generated (before charging and discharging loses) by the PV panels. One AEG PV panel is 1,456785 square meters and has an efficiency of 16%. A total of at least 48 PV panels are needed to cover the electricity shortages of an August evening.

Formula

Calculating total solar irradiance per year per m2

$$\begin{aligned} &642\ Wh\ (january) \times 31\ days + 1368\ Wh\ (february) \times 28\ days \\ &+ 2482\ Wh\ (march) \times 31\ days + 3954\ Wh\ (april) \times 30\ days \\ &+ 5182\ Wh\ (may) \times 31\ days + 5562\ Wh\ (june) \times 30\ days \\ &+ 5181\ Wh\ (july) \times 31\ days + 4424\ Wh\ (august) \times 31\ days \\ &+ 2999\ Wh\ (september) \times 30\ days + 1669\ Wh\ (october) \times 31\ days \\ &+ 788\ Wh\ (november) \times 30\ days + 467\ Wh\ (december) \times 31\ days \\ &= 1.058.551\ Wh \div 1000 \approx 1059\ kWh \end{aligned}$$

Formula

Calculating generated kWh per panel per year.

$$1059\ kWh\ per\ m2 \times 16\%\ (panel\ efficiency) \times 1{,}456785\ m2\ (panel\ size) \approx 247\ kWh$$

Formula

Calculating the quantity of PV panels needed to cover the electricity shortage between 19:00 and 22:00 in August.

$$4424\ W \times 48 \times 1{,}456785\ m2 \times 16\% = 49.496\ Wh$$

Month / Hour	Jan	Feb	March	April	May	June	July	Aug	Sept.	Oct	Nov	Dec
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	6	0	0	0	0	0	0
5	0	0	0	3	31	50	33	6	0	0	0	0
6	0	0	0	36	106	125	106	56	11	0	0	0
7	0	0	28	125	203	222	197	147	72	14	0	0
8	0	19	103	222	314	322	303	253	164	75	14	0
9	25	83	192	322	417	419	400	353	253	147	58	19
10	69	150	275	408	500	514	472	439	333	211	108	58
11	111	208	331	464	558	578	542	506	389	256	139	92
12	131	236	358	497	592	611	575	539	419	269	150	106
13	128	236	356	494	589	614	572	536	403	256	139	94
14	103	200	322	447	544	578	547	492	356	214	103	67
15	61	144	253	381	475	503	478	422	283	144	56	31
16	14	75	169	286	378	411	394	319	194	69	11	0
17	0	17	81	181	261	303	286	214	97	14	0	0
18	0	0	14	77	150	192	178	111	25	0	0	0
19	0	0	0	11	58	92	81	31	0	0	0	0
20	0	0	0	0	6	22	17	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0

Figure 8. Daily direct solar irradiance per month per hour in W/m2. Source*: Zonnestraling in Nederland: KNMI, De Kooy metingen [41].*

Generated electricity will be consumed when there is a demand for electricity to avoid losses. When more electricity is being supplied than the demand for electricity, electricity will be stored. However, during the month of August generated electricity will be stored before it is consumed. This way it is insured that there is enough electricity between 19:00

and 22:00. When the battery capacity has researched its limit, any leftover generated electricity can be consumed.

3.2.2. Scenario C – cheapest scenario

Scenario B was focused on identifying the minimal quantity of PV panels and batteries needed to cover the grid capacity shortages in 2050. Increasing the installed PV panels in scenarios B will decrease the total costs of the project since electricity from PV panels is cheaper per kWh (€0.065/kWh) than electricity from the grid (€0,171/kWh). Increasing the installed PV panels in 2050 with more than 669 will lead to the fact that more electricity is generated than is consumed or could be stored when the battery capacity is limited at 49.496 Wh. The storage capacity in scenario C is not increased since lithium-ion batteries storage systems are relatively expensive with costs ranging between €570 and €600/kWh [36].

Formula

<u>Calculating the costs per PV panels during the project lifetime of 30 years</u>

$$€142{,}60\ (prize\ per\ panel) + €66{,}67\ (prize\ per\ panel\ installation) + €0{,}02\ (eco - costs\ per\ m2) \times 1{,}456785\ m2\ (panel\ size) \times 2\ (project\ lifetime \div technical\ lifetime\ = €483{,}65\ for\ 30\ years$$

Formula

<u>Calculating the price per kWh generated electricity</u>

$$€483{,}65 \div 7410\ kWh\ = €0{,}065\ per\ kWh$$

Figure 9 illustrates the mismatch between demand and supply. The demand patterns are illustrated in figure 7 where the peak demand hours are between 07:00 and 10:00 in the morning and 18:00 and 22:00 in the evening. As illustrated in figure 8 solar irradiance is at its best between 10:00 in the morning and 14:00 in the afternoon. This is however during the hours when the electricity demand is at its lowest (figure 7). Therefore, this is defined as a mismatch between demand and supply.

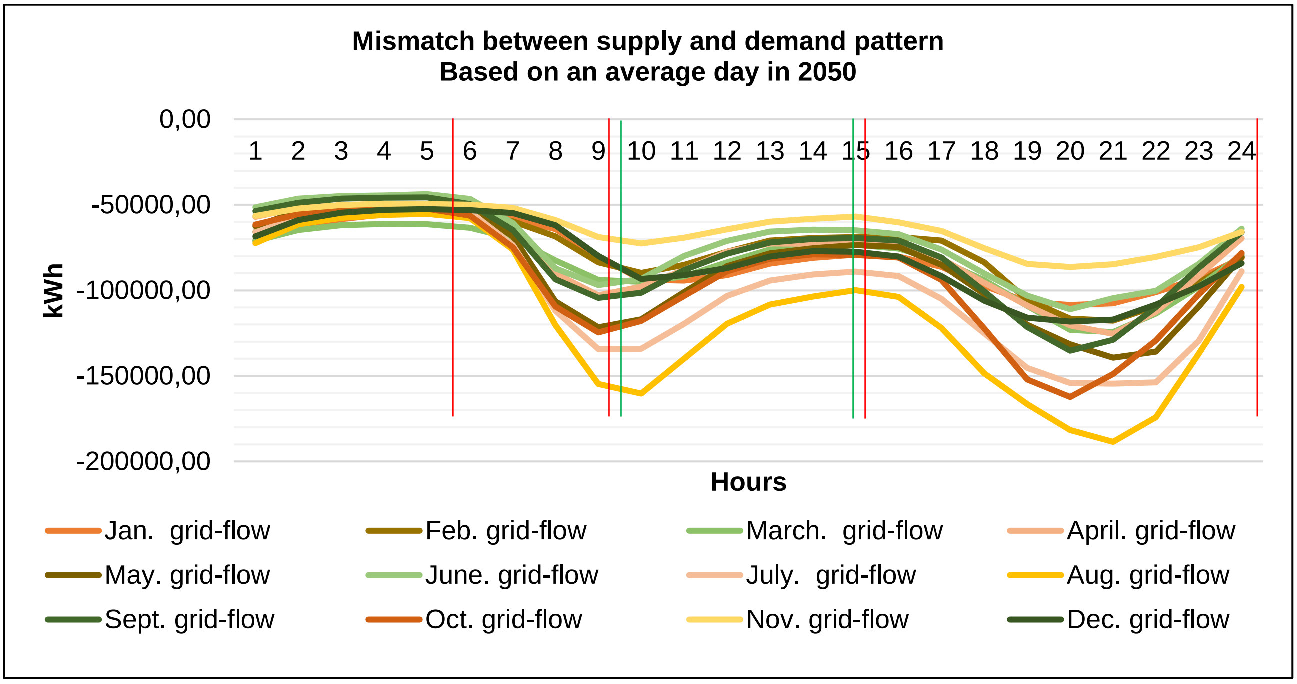

Figure 9. Mismatch between demand peak (red) and supply peak (green) patterns in 2050 (based on 48 PV panels). Anything above 0,00 needs to be stored due to a lack of demand or overproduction.

3.2.3. Scenario D - greenest scenario

This scenario is based on identifying the solution with the lowest carbon footprint by using either a grid upgrade, smart grid technologies or both to cover the future increase of electricity demand. The lowest carbon footprint is calculated by using the solver in excel. The goal was to minimize the total carbon footprint by increasing the amount of installed solar panels with a minimum of 48 panels to cope with the shortage in the electricity grid' capacity. Since no electricity can be send to the grid a total of approximately 82 batteries were needed to store the excess generated electricity when using 3001 solar panels.

3.2.4. Scenario E – battery-grid scenario

Scenario E has identified the required technical specifications by using lithium-ion batteries and electricity from the grid to cover the future increase of electricity demand. As illustrated in table 9 there is an electricity shortage between 19:00 and 22:00 of 43.712 Wh. Figure 10 illustrates at what hours, on an average day in August, there is leftover grid capacity. To cover the electricity shortage in the evening 49.471 Wh (incl. charge and discharge efficiencies) will be taken from the grid during the hours when there is a leftover grid capacity, which is between 01:00 – 18:00 and 22:00 and 00:00 and will be stored and consumed between 19:00 and 22:00. This way scenario E covers the hours when there is a grid capacity shortage after an increase in the electricity demand of 13% in 2050. To calculate the electricity needed from the grid the same formula as in calculating the necessary storage capacity is used.

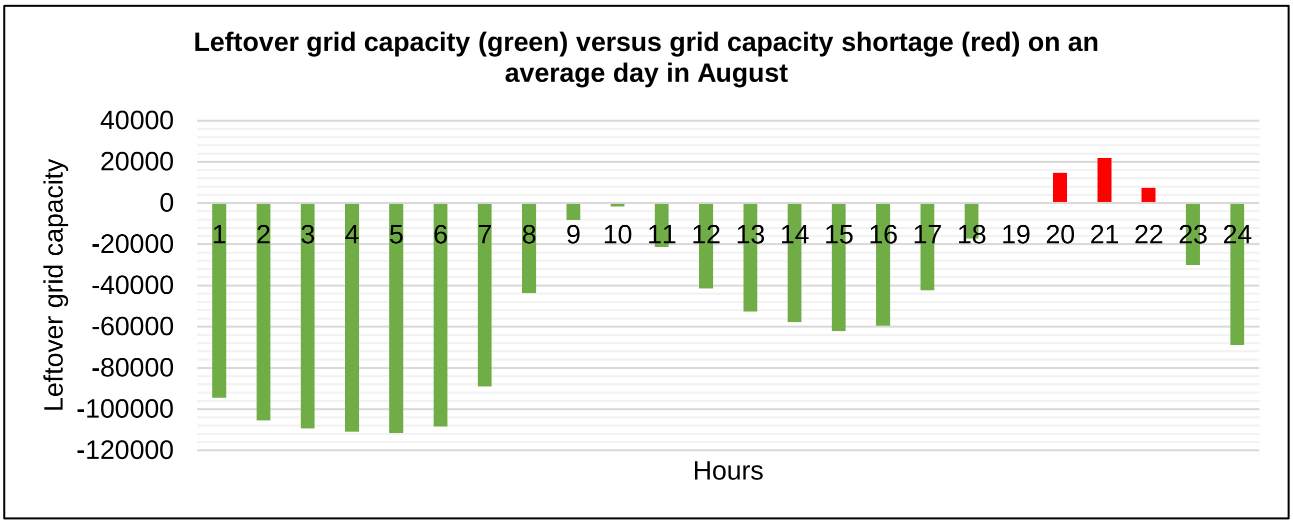

Figure 10. Leftover grid capacity on an average August day in 2050.

3.2.5. Output parameters

Table 10 shows the output parameters of the technical model for each of the five scenarios. The technical lifetime of the solar panels is 25 years. Since the project lifetime is 30 years the installed solar panels at the first year will need to be replaced after 25 years. Therefore, the output parameters show that in the total project lifetime twice as many solar panels will be needed in each scenario. This is also the case for the batteries. However, the batteries have a technical lifetime of 15 years. Moreover, the third column of table 7 shows that no whole batteries need to be installed. This is due to the fact that the technical model has rounded down the calculation to 1 decimal.

Table 7. Output parameters of the technical model.

Scenario	PV Panels	Batteries
Scenario A: Grid Scenario	0	0
Scenario B: Smart Grid Scenario	96	1.4
Scenario C: Cheapest Case	1338	1
Scenario D: Greenest Case	6002	163.6
Scenario E: Battery-Grid Scenario	0	1

Figure 11 shows the total carbon footprint expressed in $kgCO_2eq$ that is emitted in each of the scenario during the project lifetime of 30 years. Two examples of the formulas used to calculate the total carbon footprint are shown below. The input parameters used in the formulas are illustrated in appendix 8.2.

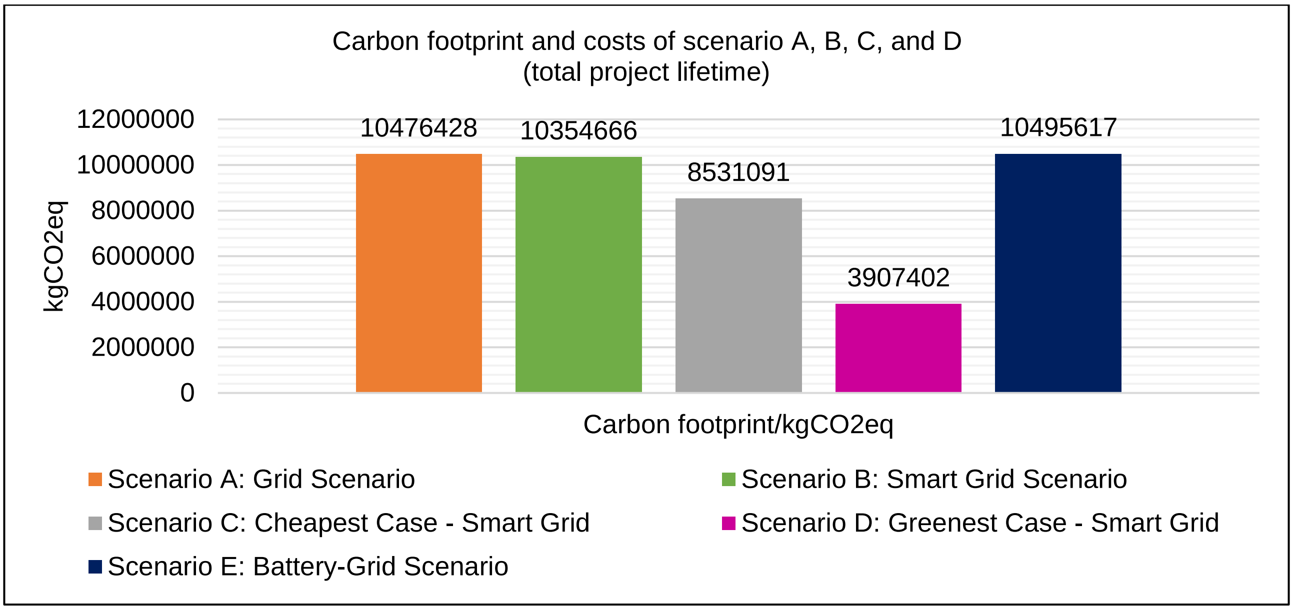

Figure 11. Total carbon footprint of each scenario after 30 years.

Formula Scenario A

$$22.214.648\ kWh\ (total\ electricity\ demand\ in\ 30\ years) \times 0{,}47\ (kgCO2eq\ per\ kWh) = 10.476.428\ kg\text{CO2eq}$$

Formula Scenario B

Electricity generated in 30 years

$$247\ kWh\ (generated\ per\ panel\ per\ year) \times 48\ (total\ panels) \times 30\ (years) \approx 355.290\ kWh\ (in\ 30\ years)$$

Electricity taken from the grid

$$355.290\ kWh\ (generated\ in\ 30\ years) - 22.214.648\ kWh\ (total\ electricity\ demand - figure\ 5) = 21.859.358$$

Carbon footprint from the grid

$$21.859.358\ kWh\ (electricity\ taken\ from\ the\ grid) \times 0{,}47\ (kgCO2eq\ per\ kWh\ from\ the\ grid) \approx 10.273.898\ kg\text{CO2eq}$$

Carbon footprint from the PV panels

$$355.290\ kWh\ (generation\ per\ in\ 30\ years) \times 0{,}07\ (kgCO2eq\ per\ generated\ kWh) \approx 26.604\ kgCO2eq$$

Carbon footprint from the batteries

$$1.4\ (batteries\ needed) \times 79.000\ Wh\ (capacity\ per\ battery) \div 1000 \times 173{,}50\ (kgCO2eq\ per\ kWh\ storage\ capacity) \approx 19.189\ kgCO2eq$$

Calculating total carbon footprint scenario B

$$10.273.898 + 26.604 + 19.189 = 10.354.666$$

3.3. Financial-Economic Assessment and Business Modelling

3.3.1. Covering initial costs

The initial costs for De Krim will be covered by different subsidies that are available for a project like De Krim' that is focused on the production of renewable energy to mitigate climate change and achieve the Sustainable Development Goals established by the United Nations. The different subsidies are established by the 'Rijksdienst voor Ondernemend Nederland' (RVO) which is a service by the Dutch Minister of Economic Affairs [42]. The following two subsidies could be addressed to cope with the initial costs of the project:

Stimuleren Duurzame Energie (SDE+)

SDE+ is focused on stimulating the production of sustainable energy such as; biomass, geothermal, solar, wind and water [43]. SDE+ compensates each generated kilowatt-hour of electricity with €0,041, when this generated electricity would be distributed to the electricity grid. However, since this is not the case is this study, the SDE+ subsidy is €0.069 per generated kWh. The period of the subsidy for solar power is 15 years.

Topsector Energie (TSE)

Projects that connect sustainability and economic growth could quality for the Topsector Energie (TSE) subsidy. TSE subsidises entrepreneurs, scientists and knowledge institutions. The types of projects that get funded by this subsidy are fundamental research, industrial research, experimental research and demonstrative research. The goal of this subsidy is to stimulate projects that are focused on realising the CO^2 reduction targets that are established in the climate agreements. TSE also contributes to increasing the Dutch employment opportunities and welfare.

The TRL of the smart grid technologies proposed in this study determine if this project will be qualified for the TSE subsidy. When the TRL is high it is less likely that a project like this one gets qualified for the TSE subsidy since the TSE subsidy is mostly focused on subsidizing projects which are relatively unknown and innovative. The combination of solar panels and batteries has a relatively high TRL, which could disqualify this project from receiving any TSE subsidy.

3.3.2. Cost-Benefit Analysis

A CBA is performed on each of the five scenarios following the guideline steps that were recommended by the 2015 European Commission's guide on CBA [35]. The input parameters used in the CBA are illustrated in annex 8.2. The complete cashflow of each scenario is illustrated in annex 8.3. It is important to know that the cash flows of the scenarios are not the usual cash flows since almost no revenue is being made during the project lifetime. Most of the revenue comes from indirect benefits such as preventing CO2 emissions and cost savings by avoiding a grid upgrade.

The CBA for each scenario will exist out of the CAPEX, OPEX, benefits, total net cash flow and the Benefit-Cost Ratio (BCR). When the BCR is more than 1.0 the benefits outweigh the costs. When the BCR is lower than 1.0 the costs outweigh the benefits [44]. The formulas used in scenario A and B to calculate the CBA are given as an example.

Scenario A – Grid Scenario

The total investment in 30 years for upgrading the electricity grid will be €7.470.134,92 existing out of CAPEX and OPEX. The biggest expenses are due to the OPEX costs of buying electricity from the grid for a period of 30 years. Furthermore, the OPEX costs include the eco-costs per kgCO2eq that is being emitted for each kWh electricity from the grid. The CAPEX costs exist out of the grid upgrade which is €2 million euros. The benefits include savings on research and development for the smart grid solution. Table 8 illustrates the total investment costs, CAPEX, OPEX, benefits, total net cash flow, and BCR of scenario A.

Table 8. Cost-Benefit Analysis scenario A.

Total investment costs	€7.470.134,92
CAPEX	€2.000.000,00
OPEX	€5.470.134,92
Benefits	€2.161,24
Total Net Cash Flow	-€7.467.973,68
BCR	0.00029

Formula

Calculating OPEX electricity demand in 30 years

$$22.214.648\ kWh\ (total\ electricity\ demand\ in\ 30\ years) \times €0,17\ (costs\ per\ kWh\ grid\ electricity) \approx €3.798.704,81$$

Calculating OPEX eco-costs in 30 years

$$22.214.648\ kWh \times €0,08\ (eco-costs\ per\ kWh\ grid\ electricity) \approx €1.671.430,11$$

Calculating total OPEX

$$€3.798.704,81 + €7.671.430,11 \approx 7.470.134,92$$

Calculating benefits

$$Total\ CAPEX\ scenario\ B \times 5\% = €2.161,24\ (savings\ on\ research\ and\ development)$$

Calculating total net cash flow in 30 years

$$€7.470.134,92\ (total\ investment\ costs) - €2.161,24\ (total\ benefits) = €7.467.973,68$$

Calculating Benefit-Cost Ratio

$$€2.161,24 \div €7.470.134,92 \approx 0,00029$$

Scenario B – Smart Grid Scenario

The total investments in 30 years for using solar panels and batteries is €5.510.780,05 existing out of CAPEX and OPEX. The biggest expenses are due to the electricity that is bought from the grid and the eco-costs of the grid electricity. The CAPEX costs exist out of: solar panel, batteries, unforeseen expenses and research and development. The OPEX costs exist out of: insurance, maintenance, electricity bought from the grid, and CO_2 emissions due to grid electricity. The benefits exist out of grid upgrade savings, SDE+ subsidy, electricity grid savings, and CO_2 savings. Table 9 illustrates the total investment costs, CAPEX, OPEX, benefits, total net cash flow, and the BCR of scenario B. The input parameters can be found in appendix 7.2.

Table 9. Cost-Benefit Analysis scenario B.

Total investment costs	€5.510.780,05
CAPEX	€90.772,08
OPEX	€5.420.007,97
Benefits	€2.103.477,50
Total Net Cash Flow	-€3.407.302,55
BCR	0.38

Formula

Calculating CAPEX electricity demand in 30 years

$$96\ (total\ panels\ in\ 30\ years) \times €142{,}60\ (costs\ per\ panel) + 96 \times €66{,}67\ (installation\ costs\ per\ panel) + 1.4\ (batteries\ needed) \times €47.400\ (costs\ per\ battery) + €2.161{,}24\ (unforseen\ expenses) + €2.161{,}24\ (research\ and\ deveopment\ expenses) \approx €90.772{,}08$$

Calculating OPEX of taking electricity from the grid in 30 years

$$21.859.358\ kWh\ (electricity\ taken\ from\ the\ grid) \times €0{,}17 \approx €3.737.950{,}22$$

Calculating OPEX for the eco-costs of taking electricity from the grid in 30 years

$$21.859.358\ kWh\ \times €0{,}08\ (eco-costs\ per\ kWh\ from\ the\ grid) \approx €1.644.698{,}09$$

Calculating OPEX for the eco-costs of generating electricity in 30 years

$$355.290\ kWh\ \times €0{,}02\ (eco-costs\ per\ kWh\ generated\ electricity) \approx €7.290{,}55$$

Calculating OPEX electricity storage in 30 years

$$1.4\ (batteries\ needed) \times 79\ kWh\ (storage\ capacity\ per\ battery) \times €61{,}55 \approx €6.807{,}43$$

Calculating OPEX insurance and maintenance in 30 years

$$€2.161{,}24\ (insurance\ for\ every\ 5\ years) \times 6 + €2.161{,}24\ (maintenance\ for\ every\ 5\ years) \times 6 \approx €25.934{,}88$$

Calculating total investment costs in 30 years

$$€90.772{,}08 + €3.737.950{,}22 + €1.644.698{,}09 + €7.290{,}55 + €6.807{,}43 + €25.934{,}88 \approx €5.510.780{,}05$$

Calculating total benefits generated electricity in 30 years

$$355.290\ kWh\ (generated\ electricity\ in\ 30\ years) \div 30\ (project\ lifetime) \times 15\ (subsidy\ lifetime) \times €0{,}069\ (subsidy\ rate\ per\ generated\ kWh) \approx €13.074{,}67$$

Calculating total benefits electricity grid savings in 30 years

$$355.270\ kWh\ (generated\ electricity\ in\ 30\ years)\ \times €0{,}17 \approx\ €62.779{,}74$$

Calculating total benefits avoided CO2 emissions in 30 years

$$355.270\ kWh\ (generated\ electricity\ in\ 30\ years) \times €0{,}08\ (eco-costs\ per\ kWh\ grid\ electricity)\ \approx €27.623{,}09$$

Calculating total benefits in 30 years

$$€13.074{,}67 + €62.779{,}74 + €27.623{,}09 \ + €2.000.000\ (savings\ grid\ upgrade) \approx \ €2.103.477{,}50$$

Calculating total net cash flow in 30 years

$$€5.510.780{,}05\ (total\ investment\ costs) - €2.103.477{,}50\ (total\ benefits) = €3.407.302{,}55$$

Calculating Benefit-Cost Ratio

$$€2.103.477{,}50 \div €5.510.780{,}05 = 0.38$$

Scenario C – Cheapest Scenario

The total investments in 30 years for using solar panels and batteries for scenario C is €4.789.521,10 existing out of CAPEX and OPEX. The biggest expenses are due to the electricity that is bought from the grid and the eco-costs of the grid electricity. The CAPEX costs exist out of: solar panel, batteries, unforeseen expenses and research and development. The OPEX costs exist out of insurance, maintenance, electricity bought from the grid and CO_2 emissions due to grid electricity. The benefits exist out of: grid upgrade savings, SDE+ subsidy, electricity grid savings, and CO_2 savings. Table 10 illustrates the total investment costs, CAPEX, OPEX, benefits, total net cash flow, and the BCR of scenario C. The input parameters can be found in appendix 7.2.

Table 10. Cost-Benefit Analysis scenario C.

Total investment costs	€4.789.521,10
CAPEX	€363.676,74
OPEX	€4.425.844,36
Benefits	€3.273.081,02
Total Net Cash Flow	-€1.516.440,09
BCR	0.68

Scenario D – Greenest Scenario

The total investments in 30 years for using solar panels and batteries for scenario C is €13.462.594,60 existing out of CAPEX and OPEX. The biggest costs are due to the batteries. The CAPEX costs exist out of: solar panel, batteries, unforeseen expenses and research and development. The OPEX costs exist out of insurance, maintenance, electricity bought from the grid and CO_2 emissions due to grid electricity. The benefits exist out of: grid upgrade savings, SDE+ subsidy, electricity grid savings, and CO_2 savings. Table 11 illustrates the total investment costs, CAPEX, OPEX, benefits, total net cash flow, and the BCR of scenario C. The input parameters can be found in appendix 7.2.

Table 11. Cost-Benefit Analysis scenario D.

Total investment costs	€13.462.594,60
CAPEX	€9.461.191,46
OPEX	€4.001.403,14
Benefits	€8.329.441,40
Total Net Cash Flow	-€5.133.153,21
BCR	0.62

Scenario E – Battery-Grid Scenario

The total investment in 30 years for upgrading the electricity grid will be €7.470.134,92 existing out of CAPEX and OPEX. The biggest expenses are due to the OPEX costs of buying electricity from the grid for a period of 30 years. Furthermore, the OPEX costs include the eco-costs per kgCO2eq that is being emitted for each kWh electricity from the grid. The CAPEX costs are relatively low since it only exists out of the costs for the battery, unforeseen costs, and research and development costs. The benefits exist out of savings on an electricity grid upgrade of €2 million. Table 12 illustrates the total investment costs, CAPEX, OPEX, benefits, total net cash flow, and the BCR of scenario A. The input parameters can be found in appendix 7.2.

Table 12. Cost-Benefit Analysis scenario E.

Total investment costs	€5.566.528,35
CAPEX	€69.678,00
OPEX	€5.496.850,35
Benefits	€2.000.000
Total Net Cash Flow	-€3.566.528,35
BCR	0.36

Figure 12 illustrates the cost division of the five scenarios. It is notable that the most expensive scenario is the scenario with the lowest carbon footprint (scenario D). Scenarios B, C, and D are all lower in costs compared to the grid upgrade (scenario A). Scenario E has the lowest investment costs which might be interesting for De Krim due to the spread of total costs throughout the project' lifetime. However, scenario C has the highest BCR (0.68) and therefore the most relevant scenario to look at.

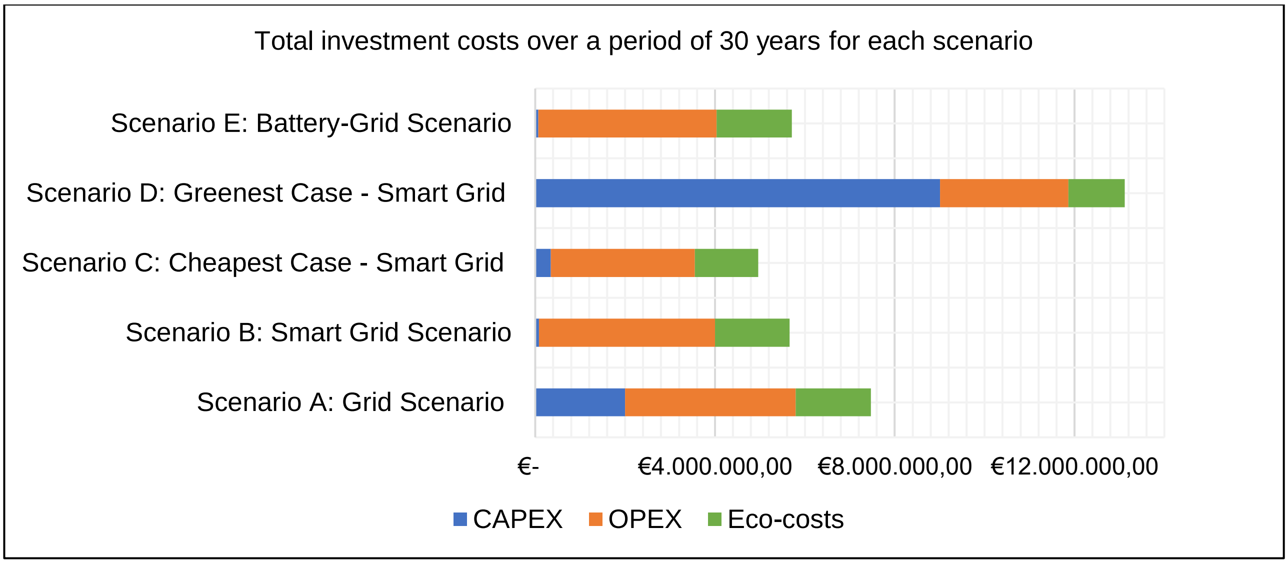

Figure 12. Illustration of the cost division of each scenario

Sensitivity analysis

A sensitivity analysis was performed by creating two cases based on scenario B. These two cases demonstrate what will happen if the electricity demand, predicted by Gasunie, is 10% lower or 10% higher in 2050. 10% is assumed to be a reasonable amount compared with the 13% increase in 30 years.

Low case
This scenario is based on a relatively low expected increase in electricity demand between 2020 and 2050. The expected electricity demand in 2050 in this scenario is based on 90% of the electricity demand used in scenario B, which results in a total increase of 1,07% in 2050 compared to the current demand.

The only hour where there is a shortage of grid capacity is at 21:00 in August in 2050. To cover this demand at least 2 PV panels and 10% of a XOLTA battery' capacity is needed. Table 13 shows the CBA in the case that the expected electricity demand in 2050 is 1,07% higher than the current demand.

Table 13. Cost-Benefit Analysis low case

Total investment costs	€5.173.555,41
CAPEX	€10.832,92
OPEX	€5.162.722,49
Benefits	€2.217.759,98
Total Net Cash Flow	-€2.955.795,43
BCR	0.43

High case
This scenario is based on a relatively high expected increase in electricity between 2020 and 2050. The expected electricity demand in 2050 in this scenario is based on 110% of the electricity demand used in scenario B, which results in a total increase of 24,03% in 2050 compared to the current demand.

In this case the shortage in the electricity grid occurs more commonly: in July between 20:00 and 22:00, in August between 09:00 and 10:00 and between 19:00 and 22:00, and in October at 20:00. The demand that determines the quantity of panels needed in 2050 to cover the electricity grid shortage is the demand in August, which is 152.624 Wh (including charge and discharge efficiency). 149 PV panels and 2 batteries are needed in the high case. Table 14 shows the CBA in the case that the expected electricity demand in 2050 is 24,03% higher than the current demand.

Table 14. Cost-Benefit Analysis low case

Total investment costs	€5.824.993,99
CAPEX	€264.559,54
OPEX	€5.560.434,45
Benefits	€2.321.214,51
Total Net Cash Flow	-€3.503.779,48
BCR	0.40

3.3.3. Business Canvas Model
Scenario C has the highest BCR of all the scenarios. A BCM (figure 13) is created as a business strategy for scenario C. The nine steps provided within the BCM identify the; key partners, key activities, key resources, value proposition, costumer relationship, channels of communication, costumer segmentation, cost structure and revenue streams.

The costumers in this business case are the residential owners of De Krim. Besides solving their expected grid congestion issues in the future this business case also: increases their RE generation, increases their self-sufficiency, lowers their carbon footprint, and avoids major costs due to an electricity grid upgrade. The key partners are the technology providers of the solar panels (AEG) and the batteries (Lithium Balance), the residential owners of De Krim themselves, TexLabs who provided this case study, and the New Energy Coalition whom hosted the investigation of this case study. The cost structure exists out of costs for buying the solar panels and batteries and the installation and maintenance of the solar panel and batteries. The key revenue stream comes from subsidies on generating solar electricity. However, this is only applicable for the first 15 years of the project.

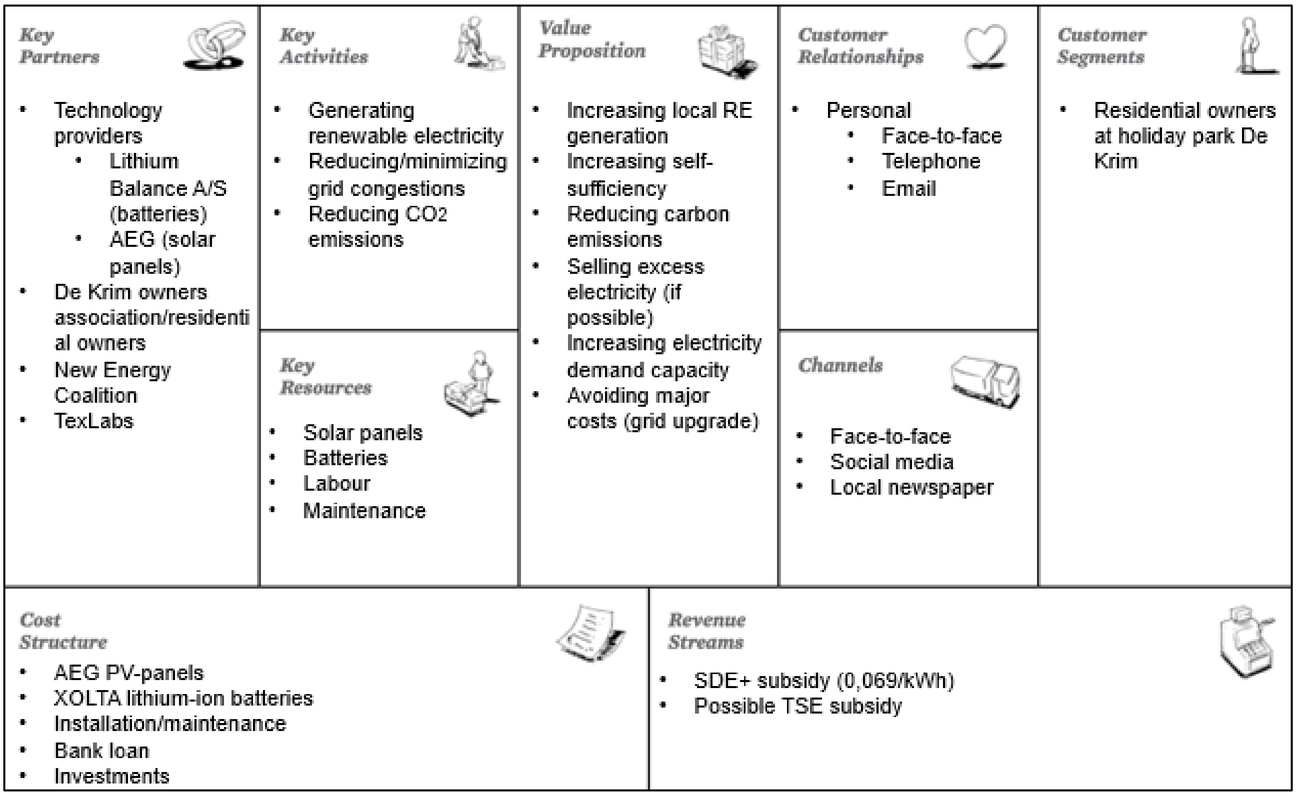

Figure 13. Business Canvas Model of scenario C.

The results discussed previously has resulted in answering the four sub-questions of this study, which evaluate will lead to the answer of the main research question.

"*Which key performance indicators determine the replicability of the smart grid technologies demonstrated within the SMILE project?* According to this study there are four main KPI's that need to be addressed to replicate smart grid technologies: the political-legal, financial-economic, technological, and societal dimensions. Especially the societal dimensions need further investigation to have a functional smart grid that can adapt and mitigates challenges and threats of the energy transition. Without the public support on the deployment of smart grids it becomes very difficult to implement such innovative technologies, even when the political, economic, technical and legal boundaries are in its favour.

"What smart grid technologies and solutions can solve the challenges faced at holiday park De Krim Texel"? A combination of solar panels and lithium-ion batteries could solve the grid congestion issues at holiday park De Krim during the months when there are grid capacity shortages. By combining a minimum of 48 solar panels and approximately 50 kWh of storage capacity the future grid congestions problems at De Krim can be solved.

"How could these technologies be implemented at holiday park De Krim Texel? The solar panels and lithium-ion batteries can be implemented at holiday park De Krim by addressing

the political-legal, financial-economic, technological, and societal dimensions. By creating a technical model and optimizing it, by changing its input parameters, the supply and demand patterns of De Krim can be simulated and optimized to fit its technical specifications. Due to the flexibility of a technical model it can easily be adjusted in order to simulate future changes in the energy system and the installed smart grid technologies. Moreover, it is more likely that this business plan will succeed when all the costs and benefits of the project are identified. This way value is created for all stakeholders which is identified to be an important aspect when it comes to replicating smart grid technologies.

"How viable are these smart grid solutions compared to the alternative of an electricity grid upgrade? If De Krim keeps increasing its electricity consumption the costs will outweigh the benefits in all the scenarios. To solve the future grid congestion problems at holiday park De Krim it is more financially viable to install solar panels and batteries then upgrading the electricity grid since the BCR of smart grid scenario C is 0.68 compared to a BCR of 0.00029 for the grid scenario. Moreover, there is a 44 kWh capacity shortage. It would be relatively expensive to open up the entire holiday park for a 44 kWh capacity shortage compared to a smart grid solution.

In short, to solve the future grid congestion problems at holiday park De Krim on Texel a combination of solar panels and batteries could provide a solution. The future bottlenecks will most likely occur during the evening hours in the month of August. By combining at least 48 AEG solar panels and 70% of a XOLTA energy storage system rack' capacity, these bottlenecks could be resolved in the case that the current electricity demand will be increased with 13% in 2050. When the electricity demand in 2050 is 10% lower than expected only 2 solar panels and only 10% of a XOLTA energy storage system rack' capacity would be needed. In the worst-case scenario, when the demand in 2050 is 10% higher than expected, 149 solar panels and 2 XOLTA energy storage systems are needed. The expected future electricity demand is an important factor within this case study. It is expected that the energy consumption in 2050 will be declined with 40% compared to the current demand. However, the electrical appliances, such as heat pumps and EV's, in the building environment will have increased in 2050. Also, due to better energy efficiency the electricity demand in 2050 will be a little bit higher than the current electricity demand. [34].

4. Conclusion

How could smart grid technologies, which are demonstrated by the SMILE project, be replicated on Texel?" Smart grid technologies could be replicated on Texel by starting with the community on Texel. A bottom-up and co-creation approach will most likely help to engage the community on Texel to cooperate and face the challenges of the energy transition to mitigate the impact of climate change. By identifying that there is a mutual problem it becomes more likely that the community on Texel will support the common goal on becoming energy neutral and self-sufficient. This way there is a bigger change for innovative smart grid technologies to be accepted and implemented. Thereafter, it is important to identify the smart grid technologies that could be implemented to solve the concerned problems by contacting experts with various experience in the technologies or implementation of these technologies. Afterwards, a technical assessment should be performed to determine the technical specifications of the identified technologies. These technologies should be modelled to fit the current and future technical specifications of the concerned area. By identifying the financial benefits of the identified smart grid technologies, it will become more likely that value is created for all stakeholders, which this study identified to be a crucial aspect of replicating smart grid technologies usefully. Moreover, it is important to identify financial solutions to finance the costs of the project. However, it seems that getting the financial support for such a project is not the problem, providing a viable business plan is. Besides, replicating smart grid technologies demonstrated by the SMILE project on Texel also contributes to Texel' goal of becoming self-supporting and a sustainable island. Finally, it is important to identify the political and legal obstacles that could hinder the project.

Smart grid technologies that are being demonstrated in pilot project could provide a meaningful solution for islands with similar topographic as characteristics but different policies, regulations, and energy markets. To replicate and implement smart grid technologies on different islands and solve balancing issues regarding the increase of RES to mitigate climate change, an island should start engaging their society by using a bottom-up and co-creation approach. Stakeholder engagement is the most important aspect when it comes the implementation of innovative solution since technology is almost never the issue. With the right technological knowledge and a viable business plan a lot of can be achieved when it comes to smartening the energy systems on islands.

5. Discussion and Recommendation

The technical model was built around four scenarios. Although, scenario C and D are similar to scenario B, and therefore do not have the technical configurations as one might expect from scenarios in a technical model since both scenarios use a combination of solar panels and lithium-ion batteries. Another point for improvement of the technical model is that the model is based on the assumption that the batteries are located near the energy demand. However, the area of holiday park De Krim is relatively large. Therefore, energy will be lost during its distribution. This needs to be considered during further research on this case study.

Total carbon footprint of the grid upgrade and expected increase in electricity demand is not considered. Furthermore, the decrease of the AEG AS-P602 PV panels efficiency is also not considered. However, according to the technical specifications of these panels after the first ten years the efficiency decreases from 90% to around 80%. This means that 10% to 20% more PV panel will be needed in reality. The decreasing efficiency of the XOLTA lithium-ion batteries during the technical lifetime was also not considered. The electricity costs per kWh from the grid were assumed to be €0,17. However, an increase or decrease in the electricity price in the next 30 years is more realistic, which could have a positive impact on the smart grid scenarios. Finally, the n=1 rule is not included. This rule states that: e.g. when one battery is needed there must always be a second one as a back-up system.

Other factors that could influence the viability of this project is societal acceptance around innovative technologies, such as smart grids, and certain policies and regulations than lean towards sustainability and less towards costs. Selling or curtailing electricity could be financially beneficial for the project since it increases the benefits by increasing revenues and reducing expenditures. If it would be possible to sell electricity to the grid extra revenues could be made. Especially when actively trading the electricity on the spot market.

The solar panels and lithium-ion batteries could become more financially viable in the future due to the technological learning curve. Solar power technology is a well-developed technology. Lithium-ion batteries however is still a relatively new technology. Nevertheless, both technologies are still improving, and future prices are still expected to decrease. The solar panel Technology Learning Curve (costs decrease over time when the technology advances), Swanson's Law [45], states that the price of solar panels decrease with approximately 20% for every doubling of the shipped volume. The technical progress, manufacturing improvements, and economies of scale has led to the volume-driven cost reduction of lithium-ion batteries [46]. A positive aspect of this project is the fact that the electricity demand of holiday park De Krim matches the electricity supply of solar panels relatively well compared to the non-tourist building environment, where consumption periods are higher in the winter months when there is a lack of solar irradiance, because the peak consumption periods are in the summer months when there is also a lot of solar irradiance.

Another alternative solution to solve the expected grid congestion problems could be Demand Response. By managing the electricity demand at certain hours, grid congestion problems could be avoided. Furthermore, using EV batteries could provide a solution since only a maximum storage capacity of 22 kWh is needed at 21:00 on an August evening. Using Smart Charging Algorithms for EV's was also mentioned during one of the interviews with expert S. Bee from Route Monkey Ltd. However, knowledge and expertise around these types of systems are still relatively scarce compared to solar panels and lithium-ion batteries.

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7. Appendix

7.1. Expert interviews: proposed smart grid solutions

Who: J. Jantzen from Samsø, 26th of September 2019.
What: Xolta BESS by Lithium Balance A/S
Why: Samsø has similar issues regarding the capacity of the electricity grid and its demand patterns due to tourism. By generating the electricity locally and consuming it locally the grid constraints were reduced, and profits were made, which are used for further investments to

improve the Balllen marina. Samsø uses PV panels and a 240 kWh Xolta BESS in the Ballen marina to cover the peak fluctuations caused by seasonal changes. By using the PV panels and the BESS in a smart way it is possible to reduce the overall costs with 6-7%. What is Smart? When the PV panels do not produce enough electricity, electricity need to be bought from the electricity grid. Buying electricity at night is cheaper than during the day. By storing this electricity in the BESS it can be used during the day when there is a higher electricity demand than the PV panels can supply.

A twenty-year payback time for the solar panels in the Ballen marina was excepted at first. However, eventually the payback time was four years. The profit that is being made during all the other years is invested in the marina for further development.

Concluding, using PV panels and lithium-ion batteries at holiday park De Krim could be feasible to solve their current limitation regarding the capacity of the electricity grid since both technologies are well developed and are still improving and future prices are still expected to decrease. The solar panel Technology Learning Curve (costs decrease over time when the technology advances) named, Swanson's Law [45], states that the price of solar panels decrease with approximately 20% for every doubling of the shipped volume. The technical progress, manufacturing improvements, and economies of scale has led to the volume-driven cost reduction of lithium-ion batteries [46]. The current price for residential lithium-ion batteries ranges between €700-€1000/kWh [47].

Who: S. Bee from Route Monkey, 27th of October 2019.
What: Predictive Algorithms for Demand Response and Smart Charging of EV's
Why: After describing the case study of holiday park De Krim Mrs. Bee concluded that it is recommended to do a feasibility study to see if demand response, smart charging/discharging of EV's by using algorithms is feasible for De Krim's future. However, most charging stations are not (yet) able to charge and discharge (bidirectional) since most hardware and software are not capable of communicating with each other. The Open Charge Alliance (OCA) leads an Open Charge Point Protocol (OCPP) to improve future development around the communication between the various technologies used within EV systems. Most of the studies are performed using either the Nissan Leaf or the Renault Zoë. It is useful to look into these EV's when performing a feasibility study.
In short, there might be a future potential using Predictive Algorithms for Demand Response and Smart Charging of EV's. However, a feasibility study needs to be performed. Current weaknesses are that there is still a lack of cyber security when it comes to the software systems of EV's. It is expected that this will improve in the coming years.

Who: I. Andrade from Madeira, 1st of October 2019.
What: Solar panels and batteries to store excess electricity and to control the frequency of the grid
Why: On Madeira they are using solar panels and lithium-ion batteries to store electricity that is generated at times that it is not consumed by the residencies. It is also used to control the frequency of the electricity grid. Like Samsø they did not recommended any type of technology. They only discussed what the problem is on Madeira and what they do to cope with this problem. However, it seems that generating renewable electricity by using solar panels for instance and storing (excess) electricity for balancing purposes, is the basis of both islands.

Madeira is currently working on a project where they can charge EV's in a smart way to reduce the load on the grid. They do this by creating charging profiles to determine when which EV must be charged. For future project they will also look into the possibility of using the EV batteries for flexibility purposes. However, this is still in early development.

Who: B. Böwadt Iversen and M. Swierczynski, 2nd of October 2019.

What: XOLTA BESS, 79 kWh p/rack

Why: Charging batteries during the day and using the electricity during the night is done at the Ballen marina on Samsø. Each battery stack has 79 kWh and you can stack up to 14 stacks (1.4 MWh). Each stack is delivered with three levels of power charge (30kw, 80kw, or 100kw). The charging efficiency ranges between 94%-96%, the discharging efficiency ranges between 94%-96%, and the round-trip efficiency ranges between 88%- 92%. The costs per kWh ranges between €570 and €600. The technical lifetime of the battery is approximately 15-20 years. Maintenance is only needed for the cooling and invertor every 3-5 years.

Both experts recommended to use several racks since the holiday park is relatively widely spread throughout the island. Having all the storage at one spot decreases the efficiency. Therefore, it is better to have one or more batteries located at different locations.

7.2. Input parameters of the technical and financial model

Variable	Quantity	Unit	Formula	Source
AEG AS-P602 PV Panels				
Panel efficiency	16,00%	percentage		[48]
Weight of PV panel	5,00	kg		[48]
Surface area of panel	1,485*0,981	m2		[48]
Price per unit (excl. tax)	142,60	euros		[48]
Technical lifespan	25	years		[48]
Watt peak per PV panel	260	Wp		[48]
Watt Peak per m2	178,48	Wp/m2	$260\ Wp\ \div (1{,}485 \times 0{,}95\ m2)$	
Costs installation 12 PV panels	800	euros		[49]
Costs installation PV panels	66,67	euros/unit	$€800 \div 12$	
Carbon footprint	2,08	kqCO2eq/100MJ		[50]
Carbon footprint	0,07	kgCO2eq/kWh	$2{,}08\ kgCO2eq\ \div 100\ MJ\ \times 3{,}6$	
Eco-costs	0,57	euros/100MJ		[50]
Eco-costs	0,02	euros/kWh	$€0{,}57 \div 100\ MJ\ \times 3{,}6$	
XOLTA Energy Storage System				
Charging power and discharging power	5000	W		[36]
Efficiency charge	94 - 96	percentage		[36]
Efficiency discharge	94 - 96	percentage		[36]
Stored energy at t=0	100	Wh		[36]
Price per kWh storage capacity	570 - 600	euros		[36]
Price per unit	47400	euros	$79000\ Wh \div 1000 \times €600$	
Battery type storage capacity per unit	79000	Wh		[36]
Technical lifetime batteries	15 - 20	years		[36]
Economic timeframe	15	years		[36]
Maintenance	3 - 5	years		[36]
Weight per kWh storage capacity	1	kg/200Wh		[50]
Weight per unit	395,00	kg	$79000\ Wh \div 200\ Wh$	

Carbon footprint	34,70	kgCO2eq/kg		[50]
Carbon footprint	173,50	kgCO2eq/kWh	$395\ kg \times 34{,}70\ kgCO2eq \div (79000\ Wh \div 1000)$	
Eco-costs	12,31	euros/kg		[50]
Eco-costs	61,55	euros/kWh	$395\ kg \times €12{,}31 \div (79000\ Wh \div 1000)$	
Electricity grid				
2018 average Dutch electricity price	0,17	euros/kWh		[51]
Carbon footprint	13,10	kgCO2eq/100MJ		[50]
Carbon footprint	0,47	kgCO2eq/kWh	$13{,}10\ kgCO2eq \div 100\ MJ \times 3{,}6$	
Eco-costs	2,09	euros/100MJ		[50]
Eco-costs	0,08	euros/kWh	$€2{,}09 \div 100\ MJ \times 3{,}6$	
Grid upgrade	2000000	euros		[20]
Project lifetime	30	years		[20]
Electricity demand 2018 (2020)	672865	kWh/y		[20]
Electricity demand increase 2050 - mid case	13,00%	percentage		Assumption
Electricity demand increase 2050 - low case	1,07%	percentage		Assumption
Electricity demand increase 2050 - high case	24,03%	percentage		Assumption
Other parameters				
Insurance	5%	CAPEX/5y		Assumption
Technical lifetime	1	years		Assumption
Maintenance	5%	CAPEX/5y		Assumption
Technical lifetime	5	years		Assumption
Research & Development	5%	CAPEX		Assumption
Technical lifetime	30	years		Assumption
Unforeseen expenses	5%	CAPEX		Assumption
SDE+ (send to grid)	0,041	euros		[43]
SDE+ (not-send to grid)	0,069	euros		[43]

7.3. Financial cashflows of the scenarios

Cashflow scenario A

	Year	2020	2021	2022	2023	2024	2025	2026	2027
T=0	0	1	2	3	4	5	6	7	8
Costs									
CAPEX									
Grid upgrade	€ 2.000.000,00								
OPEX									
Buying electricity		€ 115.059,97	€ 115.558,56	€ 116.057,15	€ 116.555,75	€ 117.054,34	€ 117.552,93	€ 118.051,53	€ 118.550,12
CO2 emissions		€ 50.626,39	€ 50.845,77	€ 51.065,15	€ 51.284,53	€ 51.503,91	€ 51.723,29	€ 51.942,67	€ 52.162,05
Total costs	€ 2.000.000,00	€ 165.686,35	€ 166.404,33	€ 167.122,30	€ 167.840,27	€ 168.558,25	€ 169.276,22	€ 169.994,20	€ 170.712,17
Benefits									
Research & Development savings	€ 2.161,24								
Total benefits	€ 2.161,24	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Total Net Cash Flow	€ -1.997.838,76	€ -165.686,35	€ -166.404,33	€ -167.122,30	€ -167.840,27	€ -168.558,25	€ -169.276,22	€ -169.994,20	€ -170.712,17

2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
9	10	11	12	13	14	15	16	17	18	19
€ 119.048,71	€ 119.547,31	€ 120.045,90	€ 120.544,49	€ 121.043,09	€ 121.541,68	€ 122.040,27	€ 122.538,86	€ 123.037,46	€ 123.536,05	€ 124.034,64
€ 52.381,43	€ 52.600,81	€ 52.820,20	€ 53.039,58	€ 53.258,96	€ 53.478,34	€ 53.697,72	€ 53.917,10	€ 54.136,48	€ 54.355,86	€ 54.575,24
€ 171.430,15	€ 172.148,12	€ 172.866,09	€ 173.584,07	€ 174.302,04	€ 175.020,02	€ 175.737,99	€ 176.455,97	€ 177.173,94	€ 177.891,91	€ 178.609,89
€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
€ -171.430,15	€ -172.148,12	€ -172.866,09	€ -173.584,07	€ -174.302,04	€ -175.020,02	€ -175.737,99	€ -176.455,97	€ -177.173,94	€ -177.891,91	€ -178.609,89

2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
20	21	22	23	24	25	26	27	28	29	30	31
€ 124.533,24	€ 125.031,83	€ 125.530,42	€ 126.029,02	€ 126.527,61	€ 127.026,20	€ 127.524,80	€ 128.023,39	€ 128.521,98	€ 129.020,58	€ 129.519,17	€ 130.017,76
€ 54.794,62	€ 55.014,01	€ 55.233,39	€ 55.452,77	€ 55.672,15	€ 55.891,53	€ 56.110,91	€ 56.330,29	€ 56.549,67	€ 56.769,05	€ 56.988,43	€ 57.207,82
€ 179.327,86	€ 180.045,84	€ 180.763,81	€ 181.481,78	€ 182.199,76	€ 182.917,73	€ 183.635,71	€ 184.353,68	€ 185.071,66	€ 185.789,63	€ 186.507,60	€ 187.225,58
€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
€ -179.327,86	€ -180.045,84	€ -180.763,81	€ -181.481,78	€ -182.199,76	€ -182.917,73	€ -183.635,71	€ -184.353,68	€ -185.071,66	€ -185.789,63	€ -186.507,60	€ -187.225,58

Cashflow scenario B

	Year	2020	2021	2022	2023	2024	2025	2026	2027
	0	1	2	3	4	5	6	7	8
Costs									
CAPEX									
AEG PV-Panels	€ 6.844,80								
AEG PV-Panels installation	€ 3.200,00								
XOLTA Batteries (incl. installation)	€ 33.180,00								
Unforseen expenses (5% CAPEX)	€ 2.161,24								
Research & Development (5% CAPEX)	€ 2.161,24								
OPEX									
Insurance (5% CAPEX)							€ 2.161,24		
Maintainance							€ 2.161,24		
CO2 emissions	€ 3.403,72	€ 49.978,34	€ 50.197,72	€ 50.417,10	€ 50.636,48	€ 50.855,86	€ 51.075,24	€ 51.294,62	€ 51.514,00
Electricity from grid		€ 113.034,81	€ 113.533,41	€ 114.032,00	€ 114.530,59	€ 115.029,19	€ 115.527,78	€ 116.026,37	€ 116.524,97
Total costs	€ 50.951,00	€ 163.013,15	€ 163.731,12	€ 164.449,10	€ 165.167,07	€ 165.885,05	€ 170.925,50	€ 167.321,00	€ 168.038,97
Benefits									
Grid upgrade savings	€ 2.000.000,00								
SDE+ subsidy (€0,069/kWh)		€ 817,17	€ 817,17	€ 817,17	€ 817,17	€ 817,17	€ 817,17	€ 817,17	€ 817,17
Grid electricity savings		€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15
Preventing CO2 emissions grid		€ 891,07	€ 891,07	€ 891,07	€ 891,07	€ 891,07	€ 891,07	€ 891,07	€ 891,07
Total benefits	€ 2.000.000,00	€ 3.733,39	€ 3.733,39	€ 3.733,39	€ 3.733,39	€ 3.733,39	€ 3.733,39	€ 3.733,39	€ 3.733,39
Total Net Cash Flow	€ 1.949.049,01	€ -159.279,76	€ -159.997,74	€ -160.715,71	€ -161.433,69	€ -162.151,66	€ -167.192,11	€ -163.587,61	€ -164.305,58

2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
9	10	11	12	13	14	15	16	17	18	19
							€ 33.180,00			
		€ 2.161,24					€ 2.161,24			
		€ 2.161,24					€ 2.161,24			
€ 51.733,38	€ 51.952,77	€ 52.172,15	€ 52.391,53	€ 52.610,91	€ 52.830,29	€ 53.049,67	€ 56.672,77	€ 53.488,43	€ 53.707,81	€ 53.927,19
€ 117.023,56	€ 117.522,15	€ 118.020,75	€ 118.519,34	€ 119.017,93	€ 119.516,53	€ 120.015,12	€ 120.513,71	€ 121.012,30	€ 121.510,90	€ 122.009,49
€ 168.756,94	€ 169.474,92	€ 174.515,37	€ 170.910,87	€ 171.628,84	€ 172.346,81	€ 173.064,79	€ 214.688,96	€ 174.500,74	€ 175.218,71	€ 175.936,69
€ 817,17	€ 817,17	€ 817,17	€ 817,17	€ 817,17	€ 817,17	€ 817,17	€ 817,17			
€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15
€ 891,07	€ 891,07	€ 891,07	€ 891,07	€ 891,07	€ 891,07	€ 891,07	€ 891,07	€ 891,07	€ 891,07	€ 891,07
€ 3.733,39	€ 3.733,39	€ 3.733,39	€ 3.733,39	€ 3.733,39	€ 3.733,39	€ 3.733,39	€ 3.733,39	€ 2.916,22	€ 2.916,22	€ 2.916,22
€ -165.023,56	€ -165.741,53	€ -170.781,98	€ -167.177,48	€ -167.895,45	€ -168.613,43	€ -169.331,40	€ -210.955,57	€ -171.584,52	€ -172.302,49	€ -173.020,47

2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
20	21	22	23	24	25	26	27	28	29	30	31
						€ 6.844,80					
						€ 3.200,00					
	€ 2.161,24					€ 2.161,24					€ 2.161,24
	€ 2.161,24					€ 2.161,24					€ 2.161,24
€ 54.146,58	€ 54.365,96	€ 54.585,34	€ 54.804,72	€ 55.024,10	€ 55.243,48	€ 55.462,86	€ 55.682,24	€ 55.901,62	€ 56.121,00	€ 56.340,39	€ 56.559,77
€ 122.508,08	€ 123.006,68	€ 123.505,27	€ 124.003,86	€ 124.502,46	€ 125.001,05	€ 125.499,64	€ 125.998,24	€ 126.496,83	€ 126.995,42	€ 127.494,02	€ 127.992,61
€ 176.654,66	€ 181.695,11	€ 178.090,61	€ 178.808,58	€ 179.526,56	€ 180.244,53	€ 195.329,79	€ 181.680,48	€ 182.398,45	€ 183.116,43	€ 183.834,40	€ 188.874,86
€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15	€ 2.025,15
€ 891,07	€ 891,07	€ 891,07	€ 891,07	€ 891,07	€ 891,07	€ 891,07	€ 891,07	€ 891,07	€ 891,07	€ 891,07	€ 891,07
€ 2.916,22	€ 2.916,22	€ 2.916,22	€ 2.916,22	€ 2.916,22	€ 2.916,22	€ 2.916,22	€ 2.916,22	€ 2.916,22	€ 2.916,22	€ 2.916,22	€ 2.916,22
€ -173.738,44	€ -178.778,89	€ -175.174,39	€ -175.892,36	€ -176.610,34	€ -177.328,31	€ -192.413,56	€ -178.764,26	€ -179.482,23	€ -180.200,21	€ -180.918,18	€ -185.958,64

Cashflow scenario C

	Year	2020	2021	2022	2023	2024	2025	2026	2027
	0	1	2	3	4	5	6	7	8
Costs									
CAPEX									
AEG PV-Panels	€ 95.399,40								
AEG PV-Panels installation	€ 44.600,00								
XOLTA Batteries (incl. installation)	€ 33.180,00								
Unforseen expenses (5% CAPEX)	€ 8.658,97								
Research & Development (5% CAPEX)	€ 8.658,97								
OPEX									
Insurance (5% CAPEX)							€ 8.658,97		
Maintainance							€ 8.658,97		
CO2 emissions	€ 3.403,72	€ 41.594,08	€ 41.813,46	€ 42.032,85	€ 42.252,23	€ 42.471,61	€ 42.690,99	€ 42.910,37	€ 43.129,75
Electricity from grid		€ 86.834,02	€ 87.332,62	€ 87.831,21	€ 88.329,80	€ 88.828,40	€ 89.326,99	€ 89.825,58	€ 90.324,18
Total costs	€ 193.901,06	€ 128.428,11	€ 129.146,08	€ 129.864,05	€ 130.582,03	€ 131.300,00	€ 149.335,92	€ 132.735,95	€ 133.453,93
Benefits									
Grid upgrade savings	€ 2.000.000,00								
SDE+ subsidy (€0,069/kWh)		€ 817,18	€ 817,18	€ 817,18	€ 817,18	€ 817,18	€ 817,18	€ 817,18	€ 817,18
Grid electricity savings		€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94
Preventing CO2 emissions grid		€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42
Total benefits	€ 2.000.000,00	€ 41.462,54	€ 41.462,54	€ 41.462,54	€ 41.462,54	€ 41.462,54	€ 41.462,54	€ 41.462,54	€ 41.462,54
Total Net Cash Flow	€ 1.806.098,95	€ -86.965,57	€ -87.683,54	€ -88.401,52	€ -89.119,49	€ -89.837,46	€ -107.873,38	€ -91.273,41	€ -91.991,39

2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
9	10	11	12	13	14	15	16	17	18	19
							€ 33.180,00			
		€ 8.658,97					€ 8.658,97			
		€ 8.658,97					€ 8.658,97			
€ 43.349,13	€ 43.568,51	€ 43.787,89	€ 44.007,27	€ 44.226,66	€ 44.446,04	€ 44.665,42	€ 48.288,51	€ 45.104,18	€ 45.323,56	€ 45.542,94
€ 90.822,77	€ 91.321,36	€ 91.819,95	€ 92.318,55	€ 92.817,14	€ 93.315,73	€ 93.814,33	€ 94.312,92	€ 94.811,51	€ 95.310,11	€ 95.808,70
€ 134.171,90	€ 134.889,87	€ 152.925,79	€ 136.325,82	€ 137.043,80	€ 137.761,77	€ 138.479,74	€ 193.099,37	€ 139.915,69	€ 140.633,67	€ 141.351,64
€ 817,18	€ 817,18	€ 817,18	€ 817,18	€ 817,18	€ 817,18	€ 817,18	€ 817,18			
€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94
€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42
€ 41.462,54	€ 41.462,54	€ 41.462,54	€ 41.462,54	€ 41.462,54	€ 41.462,54	€ 41.462,54	€ 41.462,54	€ 40.645,36	€ 40.645,36	€ 40.645,36
€ -92.709,36	€ -93.427,33	€ -111.463,25	€ -94.863,28	€ -95.581,26	€ -96.299,23	€ -97.017,21	€ -151.636,84	€ -99.270,33	€ -99.988,31	€ -100.706,28

2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
20	21	22	23	24	25	26	27	28	29	30	31
						€ 95.399,40					
						€ 44.600,00					
	€ 8.658,97					€ 8.658,97					€ 8.658,97
	€ 8.658,97					€ 8.658,97					€ 8.658,97
€ 45.762,32	€ 45.981,70	€ 46.201,08	€ 46.420,47	€ 46.639,85	€ 46.859,23	€ 47.078,61	€ 47.297,99	€ 47.517,37	€ 47.736,75	€ 47.956,13	€ 48.175,51
€ 96.307,29	€ 96.805,89	€ 97.304,48	€ 97.803,07	€ 98.301,67	€ 98.800,26	€ 99.298,85	€ 99.797,45	€ 100.296,04	€ 100.794,63	€ 101.293,23	€ 101.791,82
€ 142.069,62	€ 160.105,53	€ 143.505,56	€ 144.223,54	€ 144.941,51	€ 145.659,49	€ 303.694,80	€ 147.095,44	€ 147.813,41	€ 148.531,38	€ 149.249,36	€ 167.285,27
€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94	€ 28.225,94
€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42	€ 12.419,42
€ 40.645,36	€ 40.645,36	€ 40.645,36	€ 40.645,36	€ 40.645,36	€ 40.645,36	€ 40.645,36	€ 40.645,36	€ 40.645,36	€ 40.645,36	€ 40.645,36	€ 40.645,36
€ -101.424,26	€ -119.460,17	€ -102.860,20	€ -103.578,18	€ -104.296,15	€ -105.014,13	€ -263.049,44	€ -106.450,08	€ -107.168,05	€ -107.886,02	€ -108.604,00	€ -126.639,91

Cashflow scenario D

	Year	2020	2021	2022	2023	2024	2025	2026	2027
	0	1	2	3	4	5	6	7	8
Costs									
CAPEX									
AEG PV-Panels	€ 427.942,60								
AEG PV-Panels installation	€ 200.066,67								
XOLTA Batteries (incl. installation)	€ 3.877.320,00								
Unforseen expenses (5% CAPEX)	€ 225.266,46								
Research & Development (5% CAPEX)	€ 225.266,46								
OPEX									
Insurance (5% CAPEX)							€ 225.266,46		
Maintainance							€ 225.266,46		
CO2 emissions	€ 397.748,41	€ 13.807,20	€ 13.867,03	€ 13.926,86	€ 13.986,69	€ 14.046,52	€ 14.106,35	€ 14.166,18	€ 14.226,01
Electricity from grid		€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Electricity curtailed		€ 2.767,08	€ 2.647,53	€ 2.527,99	€ 2.408,44	€ 2.288,89	€ 2.169,35	€ 2.049,80	€ 1.930,26
Total costs	€ 5.353.610,60	€ 16.574,27	€ 16.514,56	€ 16.454,84	€ 16.395,13	€ 16.335,42	€ 466.808,63	€ 16.215,99	€ 16.156,27
Benefits									
Grid upgrade savings	€ 2.000.000,00								
SDE+ subsidy (€0,069/kWh)		€ 51.084,50	€ 51.084,50	€ 51.084,50	€ 51.084,50	€ 51.084,50	€ 51.084,50	€ 51.084,50	€ 51.084,50
Grid electricity savings		€ 115.059,97	€ 115.558,56	€ 116.057,15	€ 116.555,75	€ 117.054,34	€ 117.552,93	€ 118.051,53	€ 118.550,12
Preventing CO2 emissions grid		€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31
Total benefits	€ 2.000.000,00	€ 221.848,77	€ 222.347,37	€ 222.845,96	€ 223.344,55	€ 223.843,14	€ 224.341,74	€ 224.840,33	€ 225.338,92
Total Net Cash Flow	€ -3.353.610,60	€ 205.274,50	€ 205.832,81	€ 206.391,11	€ 206.949,42	€ 207.507,73	€ -242.466,89	€ 208.624,34	€ 209.182,65

2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
9	10	11	12	13	14	15	16	17	18	19
							€ 3.877.320,00			
		€ 225.266,46					€ 225.266,46			
		€ 225.266,46					€ 225.266,46			
€ 14.285,85	€ 14.345,68	€ 14.405,51	€ 14.465,34	€ 14.525,17	€ 14.585,00	€ 14.644,83	€ 412.453,07	€ 14.764,49	€ 14.824,33	€ 14.884,16
€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
€ 1.810,71	€ 1.691,17	€ 1.571,62	€ 1.452,07	€ 1.332,53	€ 1.212,98	€ 1.093,44	€ 973,89	€ 854,35	€ 734,80	€ 615,25
€ 16.096,56	€ 16.036,84	€ 466.510,05	€ 15.917,41	€ 15.857,70	€ 15.797,98	€ 15.738,27	€ 4.741.279,89	€ 15.618,84	€ 15.559,13	€ 15.499,41
€ 51.084,50	€ 51.084,50	€ 51.084,50	€ 51.084,50	€ 51.084,50	€ 51.084,50	€ 51.084,50	€ 51.084,50			
€ 119.048,71	€ 119.547,31	€ 120.045,90	€ 120.544,49	€ 121.043,09	€ 121.541,68	€ 122.040,27	€ 122.538,86	€ 123.037,46	€ 123.536,05	€ 124.034,64
€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31
€ 225.837,52	€ 226.336,11	€ 226.834,70	€ 227.333,30	€ 227.831,89	€ 228.330,48	€ 228.829,08	€ 229.327,67	€ 178.741,77	€ 179.240,36	€ 179.738,95
€ 209.740,96	€ 210.299,27	€ -239.675,35	€ 211.415,88	€ 211.974,19	€ 212.532,50	€ 213.090,81	€ -4.511.952,22	€ 163.122,93	€ 163.681,24	€ 164.239,54

2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
20	21	22	23	24	25	26	27	28	29	30	31
						€ 427.942,60					
						€ 200.066,67					
	€ 225.266,46					€ 225.266,46					€ 225.266,46
	€ 225.266,46					€ 225.266,46					€ 225.266,46
€ 14.943,99	€ 15.003,82	€ 15.063,65	€ 15.123,48	€ 15.183,31	€ 15.243,14	€ 15.302,98	€ 15.362,81	€ 15.422,64	€ 15.482,47	€ 15.542,30	€ 15.602,13
€ -	€ -	€ -	€ -	€ -	€ 425,50	€ 924,09	€ 1.422,68	€ 1.921,28	€ 2.419,87	€ 2.918,46	€ 3.417,06
€ 495,71	€ 376,16	€ 256,62	€ 137,07	€ 17,53	€ -	€ -	€ -	€ -	€ -	€ -	€ -
€ 15.439,70	€ 465.912,91	€ 15.320,27	€ 15.260,55	€ 15.200,84	€ 15.668,64	€ 1.094.769,26	€ 16.785,49	€ 17.343,92	€ 17.902,34	€ 18.460,76	€ 469.552,12
€ 124.533,24	€ 125.031,83	€ 125.530,42	€ 126.029,02	€ 126.527,61	€ 126.600,71	€ 126.600,71	€ 126.600,71	€ 126.600,71	€ 126.600,71	€ 126.600,71	€ 126.600,71
€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31	€ 55.704,31
€ 180.237,55	€ 180.736,14	€ 181.234,73	€ 181.733,33	€ 182.231,92	€ 182.305,02	€ 182.305,02	€ 182.305,02	€ 182.305,02	€ 182.305,02	€ 182.305,02	€ 182.305,02
€ 164.797,85	€ -285.176,77	€ 165.914,47	€ 166.472,77	€ 167.031,08	€ 166.636,37	€ -912.464,25	€ 165.519,52	€ 164.961,10	€ 164.402,67	€ 163.844,25	€ -287.247,10

Cashflow scenario E

	Year	2020	2021	2022	2023	2024	2025	2026	2027
	0	1	2	3	4	5	6	7	8
Costs									
CAPEX									
AEG PV-Panels	€ -								
AEG PV-Panels installation	€ -								
XOLTA Batteries (incl. installation)	€ 33.180,00								
Unforseen expenses (5% CAPEX)	€ 1.659,00								
Research & Development (5% CAPEX)	€ 1.659,00								
OPEX									
Insurance (5% CAPEX)							€ 1.659,00		
Maintainance							€ 1.659,00		
CO2 emissions	€ 3.403,72	€ 50.626,39	€ 50.845,77	€ 51.065,15	€ 51.284,53	€ 51.503,91	€ 51.723,29	€ 51.942,67	€ 52.162,05
Electricity from grid		€ 115.059,97	€ 115.558,56	€ 116.057,15	€ 116.555,75	€ 117.054,34	€ 117.552,93	€ 118.051,53	€ 118.550,12
Total costs	€ 39.901,72	€ 165.686,35	€ 166.404,33	€ 167.122,30	€ 167.840,27	€ 168.558,25	€ 172.594,22	€ 169.994,20	€ 170.712,17
Benefits									
Grid upgrade savings	€ 2.000.000,00								
Total benefits	€ 2.000.000,00	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Total Net Cash Flow	€ 1.960.098,29	€ -165.686,35	€ -166.404,33	€ -167.122,30	€ -167.840,27	€ -168.558,25	€ -172.594,22	€ -169.994,20	€ -170.712,17

2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
9	10	11	12	13	14	15	16	17	18	19
							€ 33.180,00			
		€ 1.659,00					€ 1.659,00			
		€ 1.659,00					€ 1.659,00			
€ 52.381,43	€ 52.600,81	€ 52.820,20	€ 53.039,58	€ 53.258,96	€ 53.478,34	€ 53.697,72	€ 57.320,82	€ 54.136,48	€ 54.355,86	€ 54.575,24
€ 119.048,71	€ 119.547,31	€ 120.045,90	€ 120.544,49	€ 121.043,09	€ 121.541,68	€ 122.040,27	€ 122.538,86	€ 123.037,46	€ 123.536,05	€ 124.034,64
€ 171.430,15	€ 172.148,12	€ 176.184,09	€ 173.584,07	€ 174.302,04	€ 175.020,02	€ 175.737,99	€ 216.357,68	€ 177.173,94	€ 177.891,91	€ 178.609,89
€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
€ -171.430,15	€ -172.148,12	€ -176.184,09	€ -173.584,07	€ -174.302,04	€ -175.020,02	€ -175.737,99	€ -216.357,68	€ -177.173,94	€ -177.891,91	€ -178.609,89

2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
20	21	22	23	24	25	26	27	28	29	30	31
						€ -					
						€ -					
	€ 1.659,00					€ 1.659,00					€ 1.659,00
	€ 1.659,00					€ 1.659,00					€ 1.659,00
€ 54.794,62	€ 55.014,01	€ 55.233,39	€ 55.452,77	€ 55.672,15	€ 55.891,53	€ 56.110,91	€ 56.330,29	€ 56.549,67	€ 56.769,05	€ 56.988,43	€ 57.207,82
€ 124.533,24	€ 125.031,83	€ 125.530,42	€ 126.029,02	€ 126.527,61	€ 127.026,20	€ 127.524,80	€ 128.023,39	€ 128.521,98	€ 129.020,58	€ 129.519,17	€ 130.017,76
€ 179.327,86	€ 183.363,84	€ 180.763,81	€ 181.481,78	€ 182.199,76	€ 182.917,73	€ 186.953,71	€ 184.353,68	€ 185.071,66	€ 185.789,63	€ 186.507,60	€ 190.543,58
€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
€ -179.327,86	€ -183.363,84	€ -180.763,81	€ -181.481,78	€ -182.199,76	€ -182.917,73	€ -186.953,71	€ -184.353,68	€ -185.071,66	€ -185.789,63	€ -186.507,60	€ -190.543,58