Ref. Ares(2017)5876066 - 30/11/2017

H2020-LCE-2016-2017

EUROPEAN COMMISSION

Innovation and Networks Executive Agency

Grant agreement no. 731249

SMILE

Smart Island Energy Systems

Deliverable D3.1
Specifications and Data Report for the Samsø Demonstrator

Document Details

Due date	30-11-2017
Actual delivery date	30-11-2017
Lead Contractor	SE
Version	Final rev0
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Input from	AAU/ET, AAU/PLAN, DTI, LIBAL, SE, SEL, SK
Reviewed by	CERTH, RINA-C
Dissemination Level	Public

Project Contractual Details

Project Title	Smart Island Energy Systems
Project Acronym	SMILE
Grant Agreement No.	731249
Project Start Date	01-05-2017
Project End Date	30-04-2021
Duration	48 months

Table of Contents

Acronyms

AAU/ET. Aalborg University, Department of Energy Technology.
AAU/PLAN. Aalborg University, Department of Planning.
BESS. Battery Energy Storage System.
COP. Coefficient of Performance.
CSFR. Climate Forecast System Reanalysis
DR. Demand Response.
DSO. Distribution System Operator.
DSM. Demand Side Management.
DTI. Danish Technological Institute.
EV. Electric Vehicle.
HP. Heat Pump.
LIBAL. Lithium Balance.
LNG. Liquid Natural Gas.
PV. Photovoltaic.
RES. Renewable Energy Sources.
SE. Samsø Energiakademi (Samso Energy Academy).
SEL. Samsø Elektro.
SK. Samsø Kommune (Samso municipality).
USEF. Universal Smart Energy Framework.
WP#. Work Package number #.
WT. Wind turbine.

1 Introduction

The core of the Samsø Regional Demonstrator is a battery energy storage system (BESS). The idea is to create a real-condition smart grid system with renewable energy sources and electric loads. The smart grid system is extended to a smart *energy* system by including heat pumps, which combine the electricity sector with the heating sector. The flagship case concerns the boats in the marina of Ballen, Samsø. The boats are to be charged with electricity by renewable energy sources (RES) by an intelligent charging system. The main proposal is to install the BESS system (240 kWh) in the Ballen marina together with a PV plant of 30 – 60 kW. A formal decision is pending, because the municipal council has to give an official approval scheduled for January 2018.

1.1 Scope and objectives

The present deliverable (D3.1) is prepared in the framework of WP3 Samsø Regional Demonstrator, and it is a forerunner for the deliverable Requirements Specifications (D3.3). The objectives of this document are:

- To provide information about the existing energy system at Samsø.
- To provide information about the legislation and political issues for establishing the demonstrator at Samsø.
- To define scenarios for Samsø under the SMILE project framework.

1.2 Structure

The existing energy system in Samsø is described in Section 1.4. An overview of the Samsø demonstrator and the objectives of the SMILE framework are presented in Section 1.5. Section 1.6 describes the rationale of the proposed Samsø scenarios. Potential deviations from the original plan, and counter-measures, are described in Section 1.7, and Section 1.8 treats legal issues concerning renewable energy and protection of personal data. Finally, Section 1.9 discusses end-user engagement.

The Danish SMILE consortium defined four scenarios, which are organised in a nested structure (onion layer structure). Scenario 1 concerns a combination of photovoltaic panels and a battery energy storage system (BESS) on the Ballen marina. Scenario 2 is an extension, which includes renewable energy generators and consumers on the Ballen *ferry* harbour. Scenario 3 includes the electric consumption and the district heating of the Ballen village. Scenario 4 includes the whole island of Samsø. The onion layer structure is meant as a managerial aid in order to better control the design and implementation phases. These scenarios are described in chapters 2-5 of the report. Finally a conclusion is made.

1.3 Relationship with other deliverables

This document is the basis for the Samsø demonstrator, and it is a forerunner for the deliverable Requirements Specifications (D3.3). Further, it defines the scenarios to be simulated in WP5 mainly concerning BESS integration, usage of demand response in relation to charging of boats and electric vehicles and usage of heat pumps. It is also related to work package 6 with regard to business models, and to WP8 concerning the evaluation of impacts of various energy scenarios for Samsø. Finally, the document addresses some of the issues to be treated regarding legal aspects in WP7.

1.4 About Samsø

Samsø is a medium-sized island according to a Danish classification; it is 11 km wide and 26 km long. Samsø is situated in the sea of Kattegat in the middle of Denmark; see the map in Figure 1. The population is 3700 permanent residents, which is the lowest level ever, see Figure 2. Evidently, depopulation threatens the community, and the ultimate goal of all activities is to contribute to the increase of the population. In 1997, Samsø won a government competition to become a model renewable energy community [8].

Figure 1. Location of Samsø (left), and four sites for marinas at the island (right). Kolby Kås is privately owned by a share holding company, while the three others are municipal.

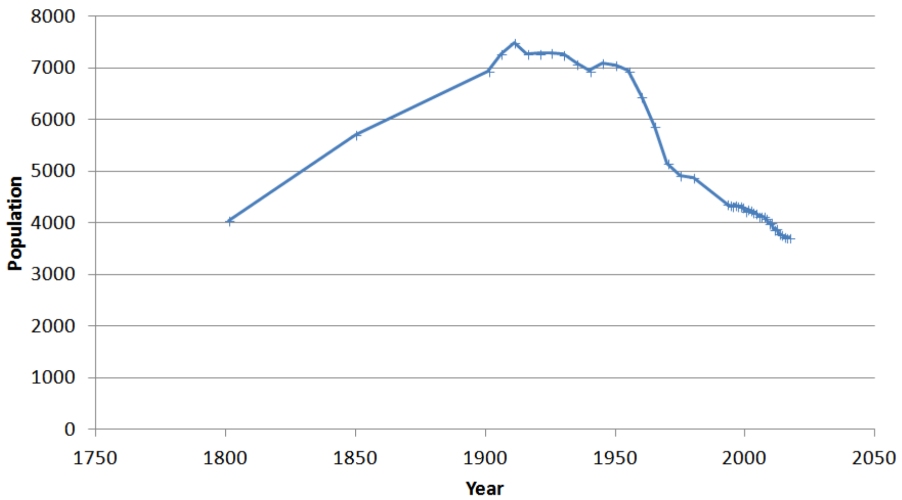

Figure 2. Samsø's population is the lowest ever.

The island produces more electricity than it consumes owing to offshore and onshore wind power, and 70% of the heat demand is covered by district heating based on biomass from local resources plus individual CO_2 neutral heating solutions. While there is not yet an issue with curtailment of renewable generation in the energy system of Samsø, there are bottlenecks which present opportunities for better management of locally generated energy, taking into account local demand. Shifting peaks in energy demand, for example, can help to stabilize and reduce energy prices for residents and visitors, as well as providing a valuable service for the local distribution system operator (DSO) by helping them to manage and balance the grid.

Recently the vision of making Samsø an island free of fossil fuels by 2030 has become a part of a new Danish project [9], which has developed scenarios to combine heating and electricity by heat pumps in the district heating as well as in buildings that are today heated by fossil fuel-based systems. Ideas for converting transportation to electric vehicles and for shifting current biomass consumption from the heating sector to the transportation sector, for instance by allowing biogas to be used by the new gas ferry to the island, are also considered. The ferry is today fuelled by liquid natural gas (LNG). The conclusion is that it is technically feasible to make a 100% fossil fuel free energy system at Samsø, by 2030. This can be done using only local wind turbines and photovoltaic (PV) systems together with the use of local biomass resources. Associated costs will stay similar to current costs, but the system could additionally contribute to local jobs creation, attract settlers, and enhance security of supply. A field study introduced smart energy to various groups of end-users [7].

New places to apply the new ideas are in the marinas on the island. There are four marinas in Samsø, see Figure 1. The Samsø demonstrator will focus on one such marina, the marina in Ballen. However, the results are also to be considered in relation to the total energy consumption of the village of Ballen and to the full energy system of Samsø.

Samsø does not have an electric power plant, and the electricity production is solely from wind turbines and PV panels. The main production (99%) is from onshore and offshore wind turbines. Samsø has cables to the mainland, and there is an exchange of power both ways, but it is mostly export. There are four district heating plants which cover about 40% of the heating demand of the whole island. The district heating plants heat water using biomass, that is, straw from the fields or wood chips from local forestry.

To give some details, Samsø has four district heating plants (2 × 1.6 MW, 3 MW, 0.8 MW), 10 wind turbines onshore (10 × 1 MW), and 11 wind turbines offshore (11 × 2.3 MW). The island often has excess electrical power and therefore exports renewable electricity to the mainland, Jutland, via two 60 kV connections, one (with two cables) to the West (max 40 MW in total) and one to the North (max 365 amp), forming a network ring. However, the northern cable is idle, since it is used only for backup. In January 2017, the export was up to 308% of the island's own consumption [12]. The surplus flows to the mainland, but the surplus helps to compensate for the fossil fuel consumed on the island.

In the past, the total energy consumed equalled the total renewable energy produced, annually. That explains why the island calls itself 100% renewable.

Samsø sets up an energy balance once every two years [1]. The energy balance has an input side — energy supply — and an output side with the demand of various groups of consumers. There are many details; but the diagram in Figure 3 provides an overview. In the diagram the total supply (915 terajoule, TJ) is consumed by the transport sector, housing, agriculture and businesses. The transport sector, including the ferries, uses almost entirely fossil fuels. The current plan is to try to install a biogas plant, which can produce green fuel for transportation. With the current prices, thermal storage (1000 EUR/MWh,th) is much cheaper than electrical storage (100 000 EUR/MWh,e) [9]. That is the reasoning behind the recommendation to combine the electric sector with the heat sector, by means of heat pumps for instance. In order to free some biomass for other purposes, heat savings in the building stock are essential. The annualised cost for 10% heat savings is 567.000 EUR per year [9]. Introduction of electric vehicles would replace expensive fossil fuel by electricity, and electric vehicles are more efficient than internal combustion engine vehicles [9]. If all cars and vans and half of the buses were replaced by electric vehicles, the socio-economic costs would drop from 30 million EUR per year to 27.5 million EUR per year (scenario 7a in [9]). Analyses like this will be developed in WP8.

The fossil energy supply is smaller than the renewable energy supply, but the renewable energy entails more losses — in district heating networks and chimneys. The ultimate goal is to dispose of the 'Fossil Energy' branch in the diagram.

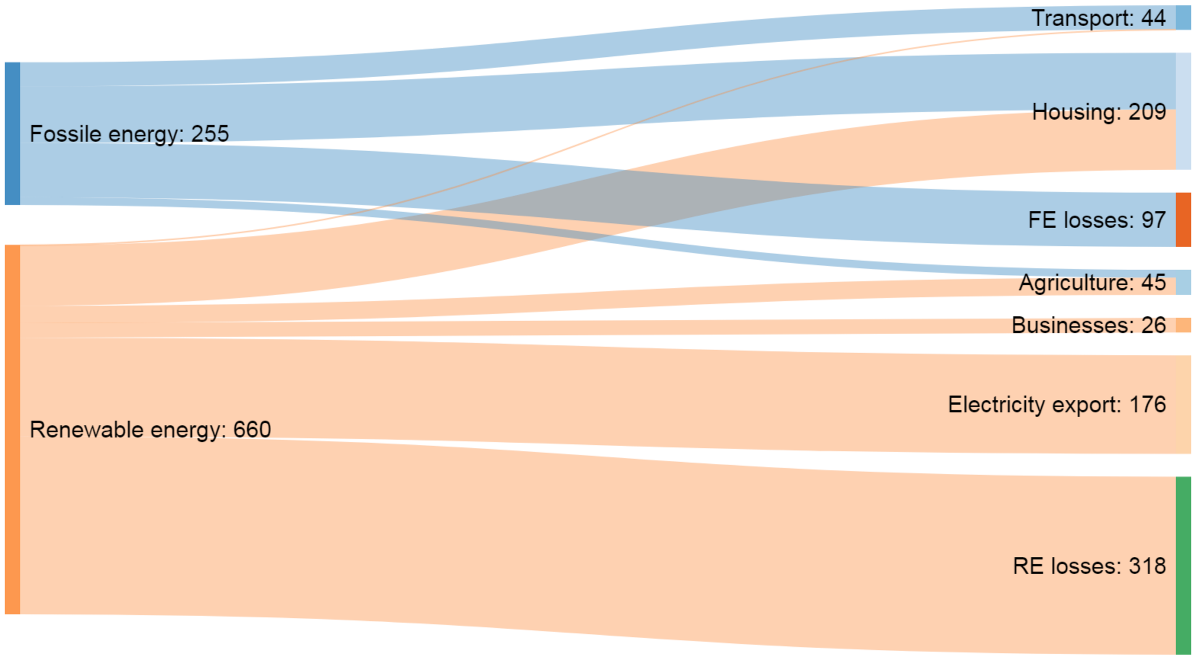

Figure 3. Aggregated yearly energy balance on Samsø. The numbers are in the unit terajoules (1 TJ = 278 MWh). By 2030 Samsø hopes to be rid of the fossil energy branch (upper part).

1.5 Samsø demonstrator overview and objectives under the SMILE framework

The current deliverable (D3.1) is defined as follows [5].

> *Document (in Danish) specifying the overall requirements, construction phases, and technical drawings to manage installers during the installation activity of the Samsø pilot system. The report will particularly include a technical description of the system architecture along with specifications. This deliverable mainly refers to Task 3.1.*

This document (D3.1) is in English, however, for the benefit of the SMILE partners. There are three overall objectives for the envisioned work in WP3.

- To make better use of the green electricity produced on the island (minimize the electricity export).
- To make the Ballen marina more attractive for sailors, tourists, and the local citizens.
- To improve the quality of life in order to attract settlers to the island.

The last two items are connected, because it is generally believed that tourism attracts settlers to the island, on a long time horizon. The *technical* objectives are:

1. To test a battery energy storage system (BESS).
2. To develop and test a control system, which allows for dynamic market prices.

The main technology focus of Samsø is to transfer energy from the electricity sector to the heat and transport sectors by means of conversion and storage devices. The complex interaction between multiple energy sources (especially renewable energy) and stakeholders requires a careful control of the electrical and thermal energy resources. There are a number of *specific* objectives, quoted in the following list [5].

1. *To **install a PV power generation system** on the pier at the Ballen marina. The electrical energy produced during the summer period from early May to early September will **cover 100% of the expected power needed in the marina in 2030**. The PV system is expected to cover the electric power consumption of boats, electric vehicles and service building at the marina. Due to the higher energy consumption **during summer months the PV power generation will end up covering app. 2/3 of the yearly energy use** at the marina.*
2. *To install a small wind turbine at the end of the pier with the purpose of supplementing the PV system during overcast periods and supplying general energy for mainly EV charging and maintenance consumption during the winter season. The **power rating should become equivalent to a yearly energy production covering app. 1/3 of the yearly energy use** at the marina.*
3. *To **cover 50% of the heating energy demands** (around 25,300 kWh) in the service building for showers and heating purposes **with excess electric power from the local PV and wind turbine** systems **using new installed heat pumps or electric water heaters and using the district heating system storage facilities**. In this way some of the energy which today is covered from the straw-fired power plant can be replaced by power generated by RES and the biomass can be used for other purposes in the future for instance making biogas for the ferry to the island. The idea is also to lower the consumption from the straw-fired plant in the summer time, thereby allocating time slots available for maintenance.*
4. *To **install a central battery energy storage system** (BESS) at the marina with the purpose of **levelling out fluctuations** from the variable power generation from RES and load peaks. Storage capacity should be sufficient to **buffer the local day-to-day energy consumption** (200 kWh). This way it will be possible to use electrical energy generated by the RES also during evening and night time where most boats are docked in the marina and energy consumption is high.*
5. *To **set up a new market model for the supply of electricity to boats and electric vehicles**. Currently boat owners do pay a fixed price per day, but the intention is that they should pay for the specific amount of energy using differentiated energy prices, depending on actual local power production. Market model concept will lean up to the Danish Market Model 2.0 and the related Universal Smart Energy Framework (USEF) ideas.*
6. *To **ensure customer acceptance and satisfaction** with the new system and demand response driven applications. The Samsø demonstration project will particularly concern both the traffic harbour and the yacht harbour.*

The SMILE project funds the BESS (240 kWh). The size is appropriate for day-to-day buffering, not seasonal storage. For comparison, the size corresponds to the capacity of ten electric plug-in cars. SMILE envisions generators (wind turbines, photovoltaic panels) and loads (heat pumps, electric vehicle chargers, boat chargers) in order to create a smart grid with producers and consumers [5]. SMILE does not fund these, but the Samsø municipality can borrow funds at a relatively low interest rate from the Credit Institution for Local and Regional Authorities in Denmark (Kommunekredit).

1.6 Samsø proposed scenarios rationale

Samsø has a master energy plan, which contains seven objectives for the year 2030, as the following quote illustrates[1].

1. *Fossil fuels are not used on Samsø.*
2. *The decentralized and flexible energy system for renewable energy production is maintained and further developed.*
3. *Fuel for transport on Samsø and to/from the island will be based on renewable energy.*
4. *Focus on significant heating savings.*
5. *To work for substantial savings on the electricity consumption.*
6. *Seize opportunities as they arise.*
7. *Strengthen and establish partnerships.*

The link in the footnote provides further explanations of each item. The SMILE project is an opportunity to test electric storage. Furthermore, the local energy system for the Ballen village will benefit, for example from the smart charging of boats and installation of heat pumps.

The work is divided into four scenarios in order to make it manageable; see Figure 4. The first scenario concerns the marina, and the following scenarios cover larger and larger areas, with the final scenario covering the whole island. The three first scenarios concern the village of Ballen, which may see future touristic development, as stipulated in the municipal plan. The Ballen marina receives 8500 visiting boats annually. Sailing boats are not allowed in the Ballen *ferry* harbour, which is the station for the island's eastbound ferry.

The municipality owns both the marina and the ferry harbour. They are in two cadastral parcels 750 metres apart. To produce renewable energy in the ferry harbour and use it in the marina is preferable, but it would be very expensive to install a sea cable and there will be some legal implications concerning the cadastral parcels.

[1] https://energiakademiet.dk/en/fossilfri-o/

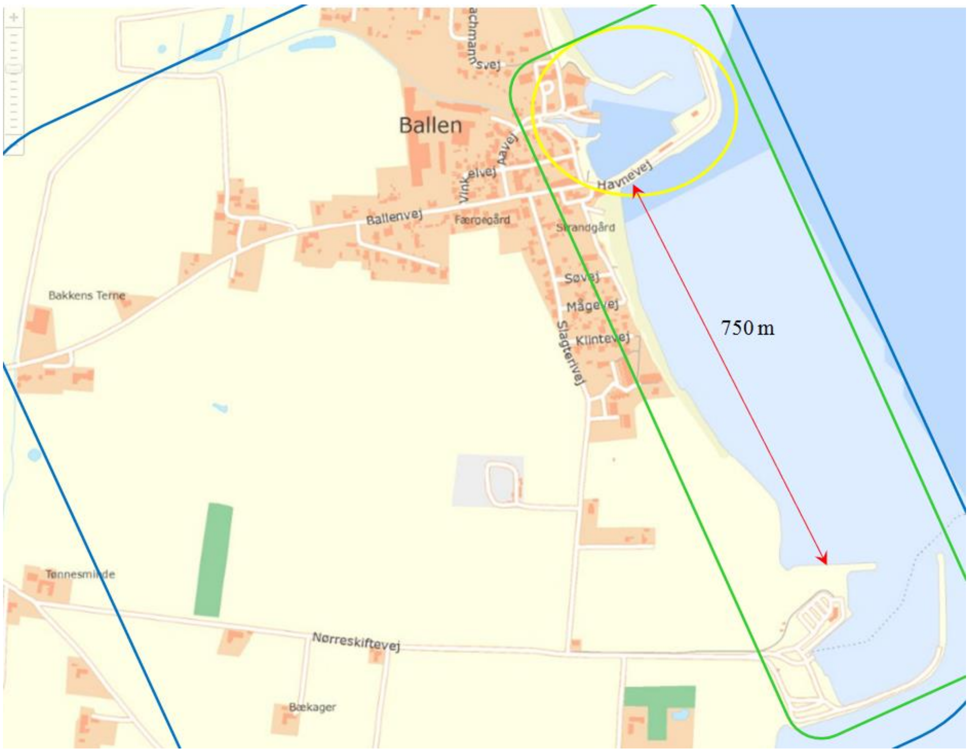

Figure 4. Scenario 1 concerns the marina (innermost region, yellow), scenario 2 concerns the marina and ferry harbour (intermediate region, green), scenario 3 concerns the Ballen village (largest region, blue), and scenario 4 concerns the whole island.

1.7 Overview of the current legislation

The Danish government taxes the consumed electricity — as stipulated in Elafgiftsloven (translation: the electricity tax law). However, renewable energy, which is directly consumed by the producer, is exempt from tax. Electricity tax represents two thirds of the billing cost for a private consumer.

1.7.1 Self-consumption

It is understood that self-consumption is via an internal cable connection. Oppositely, electricity delivered from the source via the public grid, is *not* exempt from tax. The utility company charges the tax according to the consumption measured by official meters. The tax is quite high, which makes Ballen marina's buying price (0.21 EUR/kWh) seven times the selling price (0.03 EUR/kWh). It is therefore more economical to try and consume as much as possible of the renewable energy production. The three conditions in the following list must be fulfilled in order to qualify for the tax exemption.

- The electricity is produced by RES.
- The consumption must be direct, and not passing through the public grid.
- The electricity must be consumed by the producer; they must be the same legal entity.

Nevertheless, it is possible to apply for hourly net metering at the transmission system operator (Energinet). In that case, both production and consumption are accumulated every hour by the meter, and the consumption is subtracted from the production before calculating taxes. That is, only the net sales are taxed.

A marina is allowed to mount PV panels (on a roof, for instance), and consume the electricity itself. This will not affect any other tax exemptions the marina may enjoy. However, if the marina sells some of the electricity to the grid, it may affect the tax status of the marina.

If a camp ground sells electricity to the visitors – and bills them according to meters, according to a fixed daily price, or according to a lump sum – then the electricity is taxed. It is assumed that it is valid for marinas too, so that the boat owners are obliged to buy electricity at a rate that includes the tax.

In Ballen, the marina and ferry harbour parcels are separate. It is still unclear whether it would be legal to install a sea cable that connects the two parcels in order to create an internal connection that does not pass through the public grid.

1.7.2 Protection of personal data

As part of a larger reform, the EU has issued a so-called general data protection regulation [6]. It applies from May 2018, and it should give citizens better control over their personal data. The citizens' rights include: easier access to their data, a right to erasure ('right to be forgotten'), and a right to know when data has been hacked.

Every demonstrator in SMILE has prepared a separate form regarding protection of data, in the local language, to be used when citizens are asked to provide data about their energy use or habits [11]. This is a result of the work package on ethics requirements (WP10).

In the Samsø demonstrator, the electricity consumption of some boat owners is to be measured. This can be done with a simple plug-in meter, in order to collect typical and atypical user profiles. Each boat owner must then read the information sheet concerning personal data, and thereafter sign a so-called Informed Consent Form. Other load profiles on the harbours are also likely to be recorded, for instance vehicle charging profiles.

The Ballen-Brundby district heating company owns valuable data about the heating consumption in the villages of Ballen and Brundby. SMILE cannot ask the company for personal data about the consumers, but the company will provide annual production data from the district heating plant for the needs of the project. Hourly data are not available. The district heating company is considered to have equal rights to a person, so the data must be protected the same way.

1.8 End-user engagement

Task 3.2, Citizens interaction and engagement, concerns the stakeholders and their engagement. The task is due at a later point, but started at this stage by listing possible stakeholders, as follows.

- *Citizens*. Ballen has a council of citizens. They work voluntarily with the local planning and try to improve the quality of living. The SMILE project should be aligned with their ideas and wishes for the future.
- *Boat owners*. This is a large group of end-users, and interviews with some of them will be made together with records of their charging habits.

- *Shop owners*. The Samsø economy depends heavily on tourism, and the shop owners have an interest in parking spaces, traffic, and pedestrian areas. Their financial interest in the place is seriously taken into concern since tourism plays a key role in the change of the island's population.
- *Users of the service building*. The building may be extended, and this should be in agreement with the sauna users, the boat owners that use showers and the outdoor kitchen, and the school children that perform water activities.
- *Owners of electric vehicles*. We will interview the local electric vehicle association as well as users of the municipal fleet of electric cars.
- *District heating company*. Opportunities for installing heat pumps will be explored, and this must be coordinated with the Ballen-Brundby district heating company. The company is willing to provide heating data in return for the SMILE simulations and results.
- *Harbour master*. The SMILE project has to fit into his plans and budget for the harbours. He is a key stakeholder.
- *Municipality*. The municipality owns the marina and the ferry harbour. Close collaboration with the technical department is already in place in order to develop an investment decision. The department issues technical approvals.
- *Municipal council*. The council is the political branch of the municipality. It consists of 11 persons elected by the voters on 21 November 2017. The SMILE partners must seek approval by the politicians.
- *The electricity company*. The utility company (NRGi) issued a letter of support, but the SMILE renewable energy plant has to be registered by them.

The board of the Ballen-Brundby district heating company has already been informed about SMILE. Shop keepers on the marina have also been informed about the SMILE project objectives. The same applies to the harbour master, who is participating in the local SMILE meetings. The chairman of the Ballen citizens' council is also aware of SMILE's scope and proposed solutions. Once the municipal council has approved the overall plans, the citizens' council and the shop owners can be approached in a broader manner.

2 Scenario 1, The Ballen Marina

In Scenario 1, the integrated smart grid system mainly focuses on the electric demand at the marina; see the map in Figure 5. The electrical loads are inserted on the map. There is a single meter which connects the parcel to the public grid.

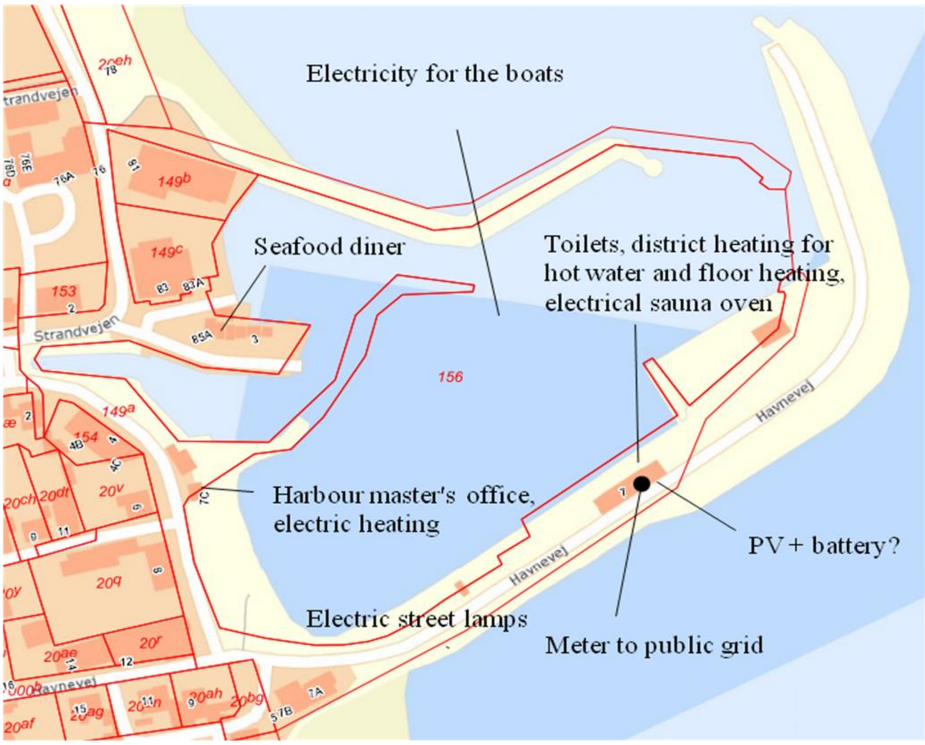

Figure 5. The marina parcel with its energy consumers. The parcel is misaligned, because the harbour was rebuilt after the cadastral map was drawn.

2.1 Current state of technology

The marina has many piers equipped in total with more than 200 electrical sockets. Figure 6 shows an example of an electricity supply with eight sockets (alternating current): four are single-phase (230 V), and four are three-phase sockets (400 V). The fuse box contains 6, 10 and 16 amp fuses. The smaller sizes indicate that the power capacity is limited. It is believed that a demand side management system will be able to charge the boats without tripping the fuses thus obviating the need for strengthening the electric network on the harbour. The service building has toilets, showers, a washing machine, and an electrically heated sauna. All rooms in the service building have underfloor heating. Floor heating and hot water depend on district heating, which is based on local biomass (a straw-fired plant, 1.6 MW). A seafood diner uses electricity, but it is only open from April to October and 14 days around Christmas.

Figure 6. Example of an electricity supply for the boats.

The electricity consumers are all behind one meter to the public grid. Therefore, a small-scale, genuine smart grid can be created within the current legislation. More specifically, the legislation allows the production of RES electricity and the use of it within the parcel without paying the usual high electricity tax. However, energy from the battery cannot be sold to the grid, because battery power is ineligible as a RES.

Today, the energy demand in Ballen marina is very inconsistent as it is dominated by the demand from berthed yachts and the associated tourism. This results not only in significant fluctuations on a daily basis, but also significant seasonal variations as tourism has its peak in the summer. In Figure 7 the electricity demand for the marina is shown for a full year. The annual consumption is about 100.000 kWh. This amount involves the consumption in the service building, its sauna, the harbour master's office with a small electric heater, the seafood shop and diner with cooling and heating, lighting at the marina, and connections to yachts in the marina. Figure 7 shows that the main loads are in the summer months, especially in July and August, where more energy is needed for the supply of the boats. Peaks are also seen in May and June, mainly in weekends and on holidays (Prayer Day, Ascension Day, Whit Sunday and Whit Monday). Also Easter is visible in April 2017, which again means tourists in the marina. Figure 8 enlarges a few days to show the daily variation. One of the days is Ascension Day (5 May 2016), and evidently the demand increased that afternoon until the end of the weekend.

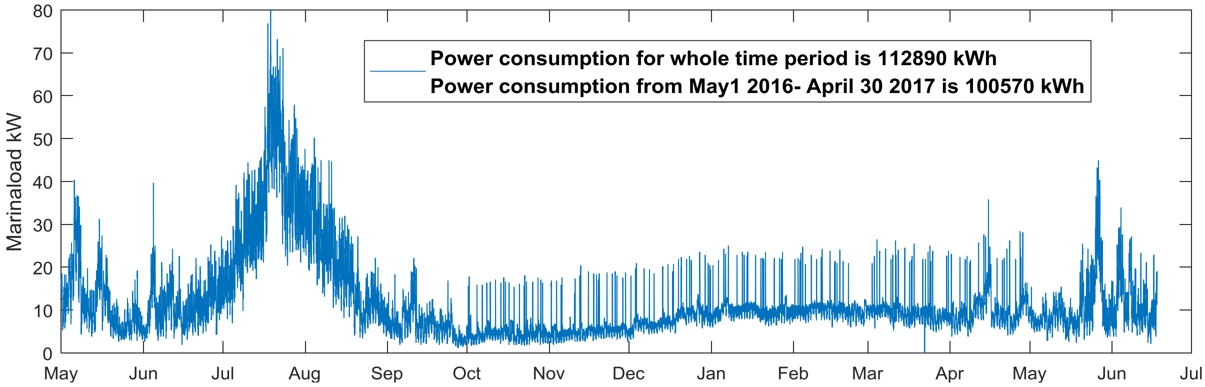

Figure 7. Historical electricity demand in kilowatt in the marina during the period from 1 May 2016 until 19 June 2017.

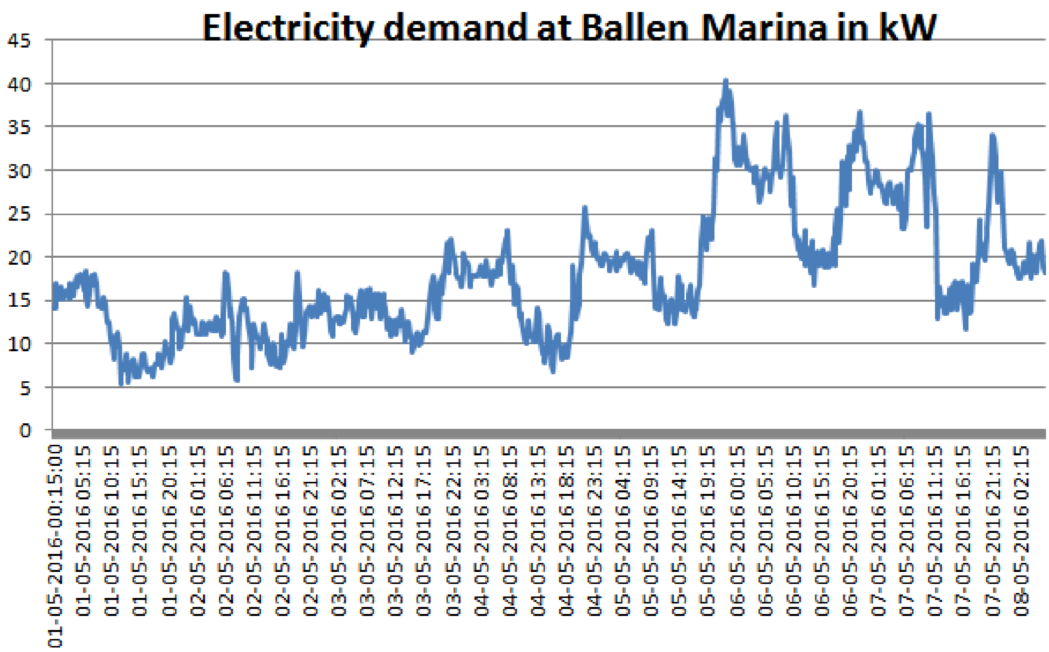

Figure 8. Historical electricity demand in kilowatt (kW) in Ballen from 1 May 2016 until 8 May 2016.

2.2 Current energy flow considerations

This section describes the electric side of the energy flow. Details about the economic side, associated with electricity costs, follow in a later section in the form of cash flow analyses.

To solve the issue of fluctuation in the energy consumption, the demonstrator will seek to implement an integrated energy system at the marina and its surroundings, comprising the renewable generation (PV panels) linked to a central storage unit (BESS) and the distributed battery storage on the boats. The effective co-operation of boat charging and other energy storage will be supported by a demand side management (DSM) system.

The current situation — where boat charging is included in the fixed, daily harbour fee — is something that has to be dealt with. The energy consumption is not measured, so there are no data concerning annual consumption, charge per hour, or similar. It would be preferable if the price was a correlate of the actual consumption and the time of the day, so as to support the daily needs of the grid's flexibility. This entails the measuring of consumption at each socket.

The idea is to integrate more RES energy by means of a PV plant on the pier. Further, the plan is to install a BESS close to the service building, in order to store excess power from the PV plant during daytime, and deliver power during the evening and nights when no energy is produced. Some energy flows are preferable, such as energy transfer from PV production to the BESS or directly to the consumers, or from BESS to consumers. Others are less preferable such as energy flow from the PV to the grid or from the grid to BESS when PV power is inadequate. Selling from the BESS to the grid is forbidden under the current legislative framework. The energy management system should optimise the flows to achieve the most self-consumption of the PV power.

2.3 Sample recruitment

The expected electrical setup for the energy system at Ballen marina is shown in Figure 9. The scenario is organized by the Samsø municipality (SK), Samsø Energy Academy (SE) and Samsø Elektro (SEL). Further partners to be involved are the Danish Technological Institute (DTI) and Lithium Balance (LIBAL) regarding the battery storage system; Aalborg University (AAU) regarding simulation and control issues; Route Monkey and Vcharge regarding the DR method.

The users (the boat owners) of the systems will be activated as described in Section 1.8.

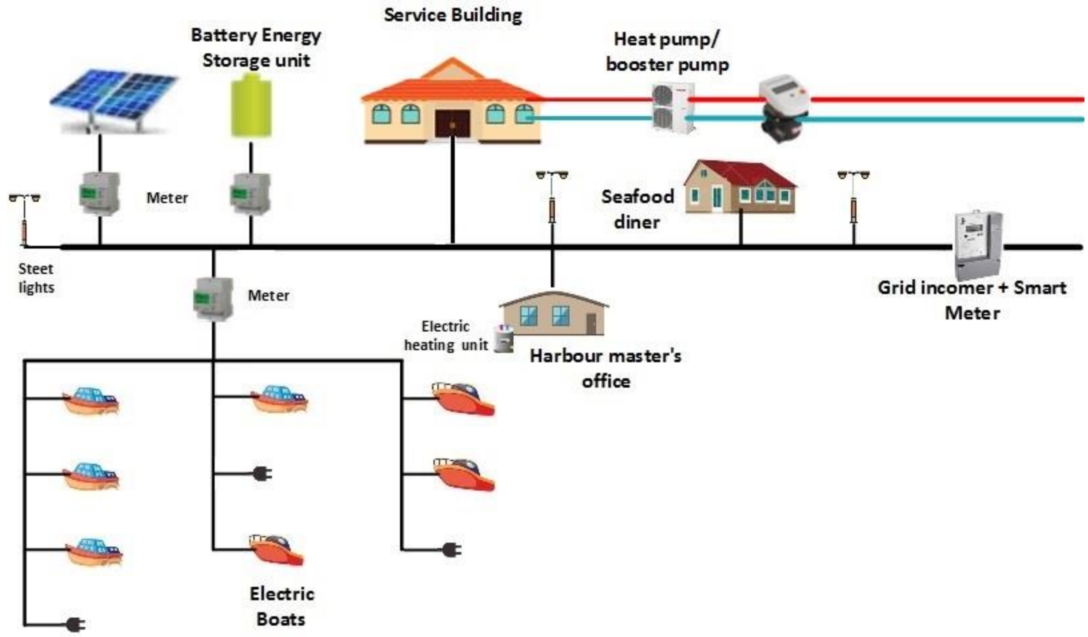

Figure 9. Schematic of electricity and heating system for the marina in Ballen.

2.4 Main tasks

The studies are based on the following main research goals:

- Optimization of the sizing of the PV-BESS system, so that the PV penetration is maximized, and the investment is still feasible.
- Installation of a 240 kWh BESS system, where 80% (192 kWh) are available for operation, based on the budget of the project, as this is the optimal size according to the initial calculations.
- Determination of demand response (DR) techniques for charging the boats in an effective way, in order to minimize the peak consumption and level out power fluctuations.

The sizing of the PV system was supported by AAU/ET, who simulated the energy flow in several case studies, based on historical data collected by the Samsø partners [10]. Figure 10 and Figure 11 show the exchange with the grid with two sizes of a PV plant selected from the set of simulation runs: 24 kW and 48 kW. The simulations are useful, because they indicate the annual sale and purchase of energy to and from the grid, respectively. The buying price (0.21 EUR/kWh) is higher than the selling price (0.03 EUR/kWh), so it is preferable to spend the energy inside the parcel, rather than selling it to the grid. This is elaborated in a cash flow analysis in the following section.

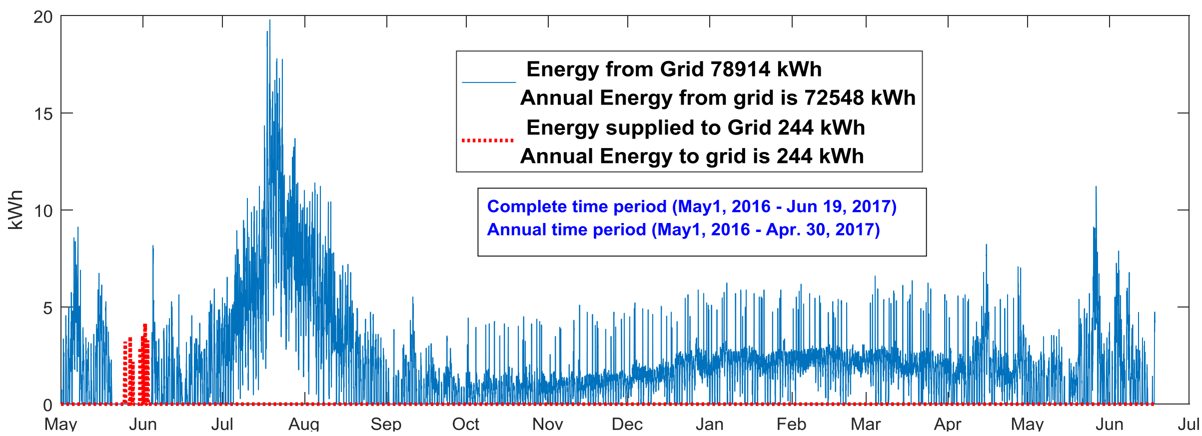

Figure 10. 24 kW PV + 200 kWh battery simulation with data from 2016-17 [10].

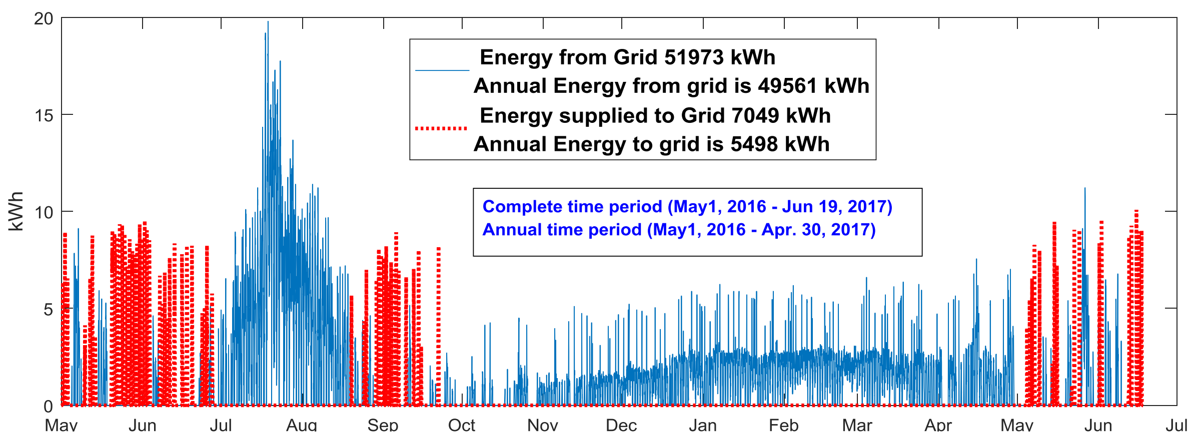

Figure 11. 48 kW PV + 200 kWh battery simulation with data from 2016-17 [10].

2.5 Cash flow analysis of a PV plant investment

SE designed a tool (in Excel) that constructs the cash flow stream over the lifetime of the PV panels. The graph in Figure 12 shows four items in one picture: the initial investment, the payback period, the lifetime, and the final profit. The picture immediately changes when the input parameters are changed. The cash flow analysis is the primary decision support regarding sizes and configuration.

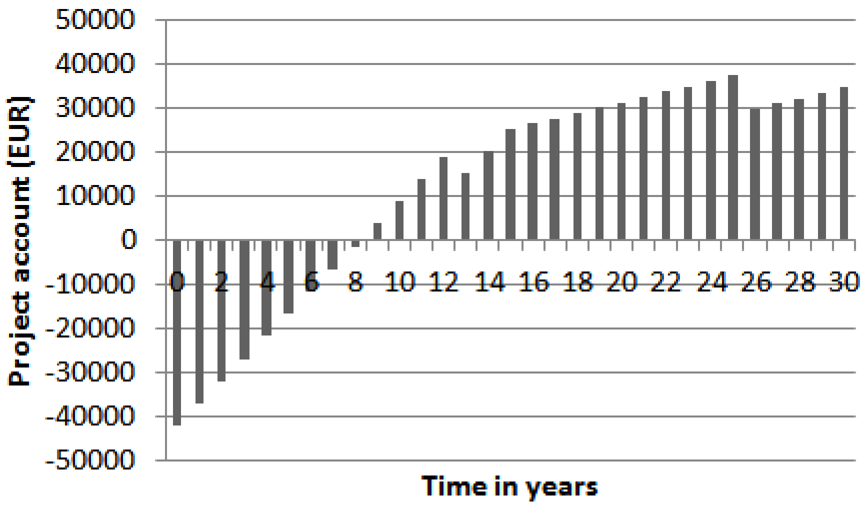

Figure 12. The balance of the project account over time. It shows the standard case of an investment in a 30 kW PV plant, connected to a 240 kWh BESS.

The technical-economic calculations include, among others: investment prices, selling and buying prices for electricity, the price of a loan (25 years), the degradation profile of the PV panels and the lifetime of the battery. The municipality asked to exclude advanced factors, such as inflation and time value of money, in order to keep the calculations transparent. Appendix A shows the full spreadsheet report.

The primary decision criterion is the payback period: It must be less than 20 years. This is an internal municipal rule concerning all investments. The calculations show that this is indeed feasible, up to a certain size of the PV plant. It is difficult to define a technically optimal size of the PV plant, but it is possible to find a size which is economically optimal. There are other decision parameters as well, such as space limitations, maintenance, appearance, loss of parking spaces, and public acceptance of a potentially large PV plant in the idyllic Ballen marina sensitive to tourists. It is a multi-criteria decision, which requires many meetings and simulation experiments.

Table 1 summarizes the parameters and the relevant technology data. Note that the technical lifetime of PV panels is 30 years [2], while the maturity of the loan is 25 years, which is the maximum period the municipality will accept. The lifetime of the battery is just 15 years in comparison.

The battery is funded by SMILE, while the PV plant is funded by the municipality, provided that: (1) it is economically viable, and (2) there is an agreement by the municipal council. The payback period is the main criterion, but the plant must also be accepted by the local society. The cash flow stream is as long as the lifetime of the PV plant (30 years). The battery, which stores PV power in the daytime and releases it during the afternoon and night time, improves the economic viability of the investment. The simulations show that there are savings, which could be used to finance other installations, for example the boat charging system, yet another building for PV panels, or a small wind turbine.

The reference case is 'business as usual', where the electricity for the marina is purchased from the grid at the market price. The buying price is fairly high, due to taxes, even though the harbour can get a refund for the value added tax (25% VAT). The project case of the cash flow simulation includes the PV investment, and an option to invest in a grid connected wind turbine. It is infeasible to build a wind turbine on the marina due to likely opposition from the boat owners and the municipal council. However, the savings due to the PV plant could pay for a wind turbine on the ferry harbour, connected to the grid.

The calculations rest on some assumptions divided into three cases, corresponding to different choices of the input parameters: (1) best case, (2) standard case, and (3) worst case. The following list describes the standard case.

- The rated power of the PV panels can be chosen freely, and adjusted to achieve a specific goal, such as a given payback period.
- The lifetime of the PV plant is assumed to be 30 years, and the lifetime of the battery is 15 years in the standard case.
- The PV inverter is replaced every 13 years.
- Technological data are official Danish numbers ([2, 3]).
- Prices are from the same catalogue, but partner SEL has also estimated some prices, which are included in the worst and best cases.
- The service building faces 22 degrees away from south toward east; thus the PV production is slightly less than maximal.
- However, the annual production is relatively high on Samsø compared to the mainland.
- The electricity prices are marginal prices, that is, the price of the last saved kilowatt-hour, disregarding subscription fee.
- Overflow electricity is sold to the grid at a low price (0.03 EUR/kWh).
- Electricity prices will most likely grow, but we include a very cautious growth rate (0.25 percent per year). It can be adjusted.
- The PV yield will degrade somewhat over the years (0.63%).
- Nothing is assumed about the battery (such as losses, degradation, or temperature dependency). The calculations rely on simulations by partner AAU/ET, who estimated the annual grid export/import depending on discrete sizes of the PV plant. The spreadsheet interpolates between the results in order to allow for a continuous adjustment of the PV size.
- Project interest rate, inflation, and discounting are omitted, since the municipality favours transparency over accuracy.
- The loan is from the Danish municipal fund (Kommunekredit) at a low interest rate (1.61% per year). The loan lasts 25 years, which is the max acceptable maturity period.

The results are sensitive to changes of the parameters, and the worst case and best case scenarios help to give an idea of the extremes of solutions (the envelope). After a number of meetings between the Samsø partners, the following is concluded:

- It is the available space that determines the size of the PV plant.
- The current service building provides enough roof space for a 30 kW plant.
- The payback period (9 years) is then well within the limit.

- Another building, or a new building, may accommodate yet another 30 kW array.
- In that case, the payback period will still be satisfactory, and the economy will be more robust towards uncertainties.
- A conventional wind turbine on the marina is ruled out, due to non-technical barriers.

Thus, a minimum PV plant of 30 kW is feasible. A new building may be established, doubling the plant size, but an architect must first make a sketch. The municipal officers must describe the project in a so-called municipal case, which must be presented to the municipal council for approval.

Table 1. Technology data for PV panels under 100 kWp.

Parameter	Value	Comment
Lifetime	30 years	[2]
Space requirements	6.5 square metres per kWp	[2]
Specific investment	1190 EUR/kWp	[2]
- including inverter	303 EUR/kWp	SEL
Fixed O&M	12 500 EUR/(MWp*yr)	[2]
Full load hours at Samsø	1020	Own empirical estimate
Buying price of electricity	0.21 EUR/kWh	Municipal electricity bill
Selling price of electricity	0.03 EUR/kWh	Existing municipal PV panels
Degradation due to age	0.63% after two years	Scheuten panels data sheet
Interest rate on load	1.61%	Annuity loan, kommunekredit.dk
Duration of loan	25 years	Max acceptable by the municipality

2.6 Summary of hardware and software components

This scenario requires a new BESS system to be installed at the marina. The size of this should be 240 kWh, and the rated power of the inverter is 50 kW. A PV plant is to be installed; the size of this will be at least 30 kW and at most 60 kW.

Further, remotely controlled switches are to be installed at the connection points for the boats at the piers. These are to be used for the demand response and will be further specified in D3.3 and the control method in Task 5.1.

The switch boxes will be developed by VCharge and the intelligent software for controlling the demand response is to be developed by Route Monkey.

The following technologies will be provided by SMILE partners:

- Lithium Balance: Battery storage system including load controller and battery management system
- Vcharge and Route Monkey: Charging control of the boats and the demand response application

3 Scenario 2, Include the Ferry Harbour

The ferry harbour will be included in this scenario. The ferry harbour has already some extra installations, and there is enough space for further installations. Being an industrial harbour, it is less sensitive to non-technical barriers.

3.1 Current state of technology

Figure 13 shows the ferry harbour parcel and its generators and loads. The idea is to include the existing heat pump that covers the heat demand in the terminal building. It is possible to build a wind turbine, but the selling price of the electricity will be low.

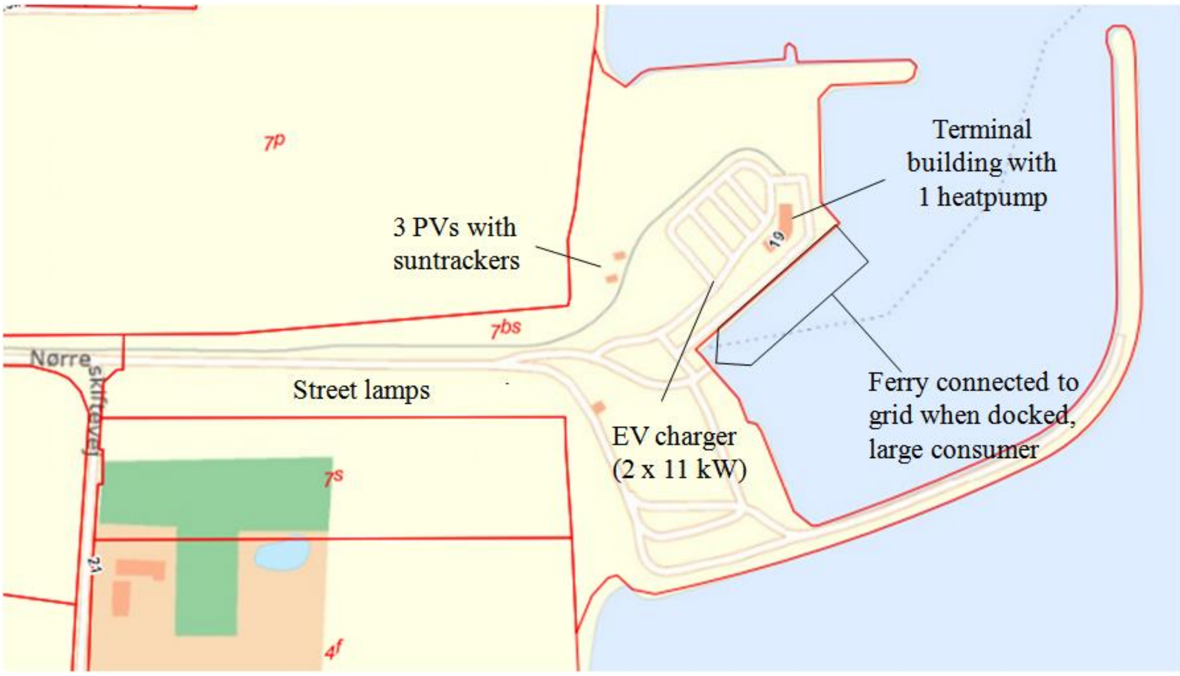

Figure 13. The ferry harbour parcel with its existing electrical consumers and generators.

To simulate this scenario, the consumption and production at the ferry harbour has to be taken into account. This includes the terminal building, the heat pump in the building, street lamps, the charging station for electric vehicles (2×11 kW), and the existing PV plant (12 kW).

Figure 14 shows the energy bought from the grid and the energy sold to the grid. When the PV production exceeds the immediate demand, energy is sold to the grid on an hourly basis. Apparently, there is a sale of energy every month, all year round, despite the low PV production during the winter months. The reason must be that PV production, during daytime, is larger than the demand during daytime. The figure shows only the flow to and from the grid, as reported by the meter; we cannot see the self-consumption of PV energy behind the meter. In order to do so, we need data for the synchronous PV production as well.

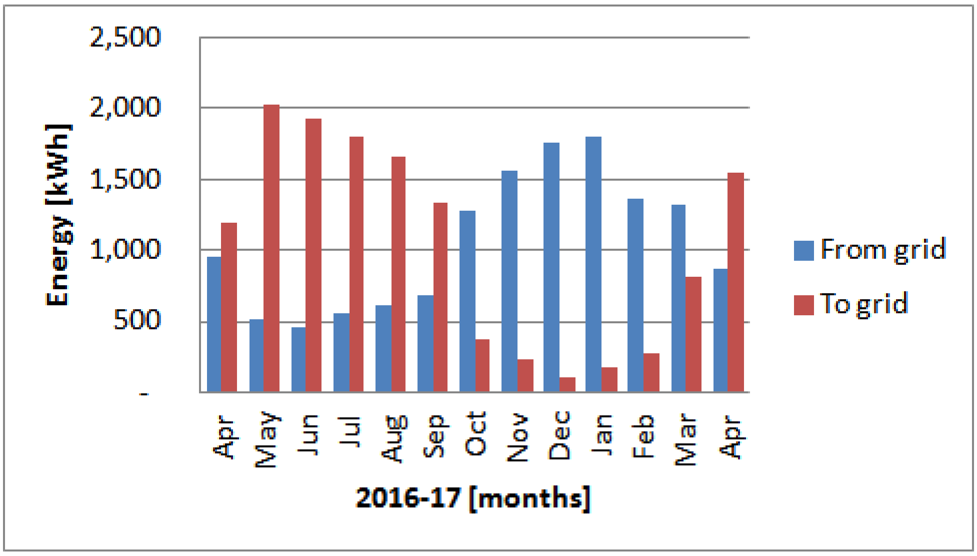

Figure 14. Measured energy to/from the grid in the ferry harbour, recorded by the public meter.

3.2 Sample recruitment

The expected electrical setup for the energy system including also the ferry harbour is shown in Figure 15. The demonstrator is organized by the local participants on Samsø, that is, the municipality (SK), Samsø Energy Academy (SE) and Samsø Elektro (SEL). Further partners to be involved in this scenario are DTI and Lithium Balance regarding the battery storage system, Aalborg Unviersity regarding simulation and control issues, Route Monkey and Vcharge regarding the demand response method.

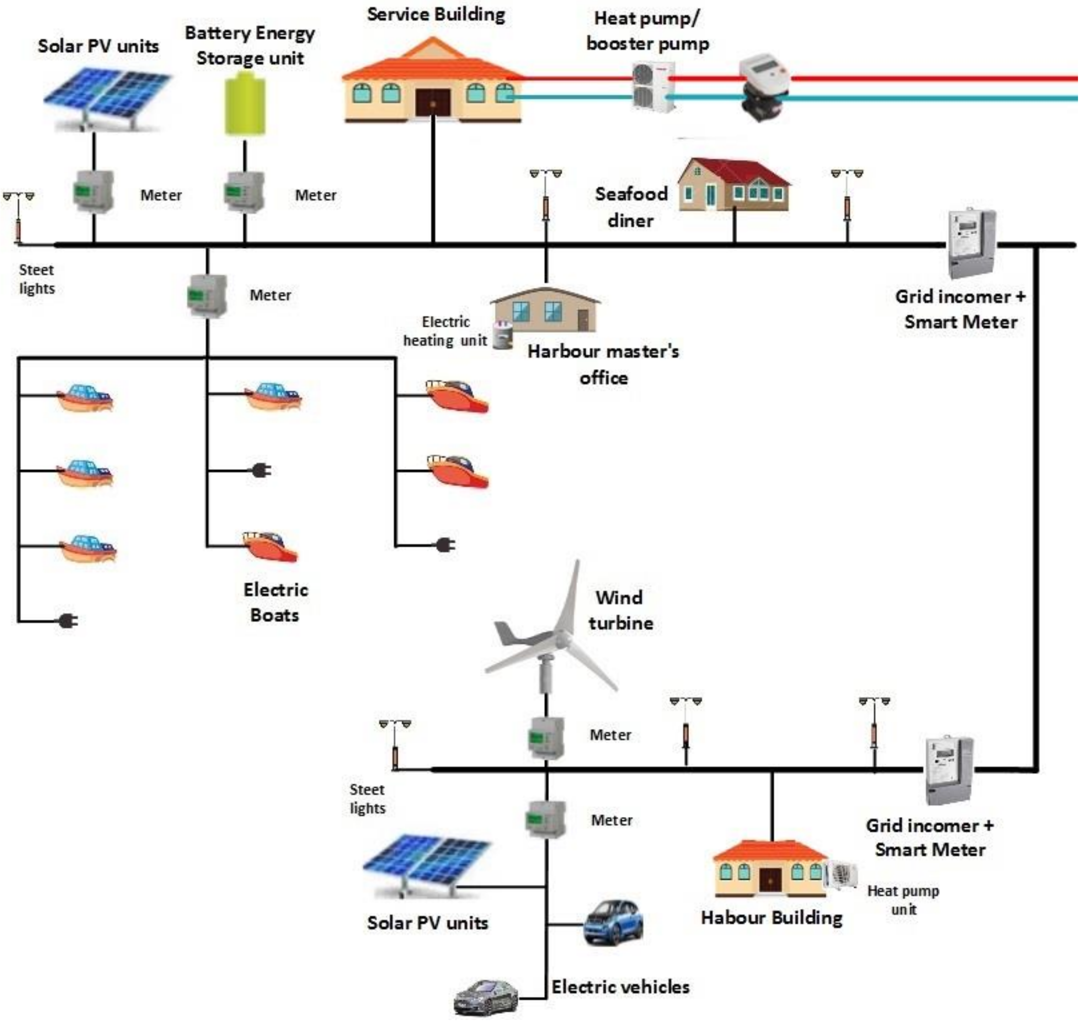

Figure 15. Schematic of electricity and heating system for both the marina and the ferry harbour.

3.3 Main tasks

In this scenario including the ferry harbour the following research goals are to be considered.

- Including in the simulations the load of the existing heat pump, EV charging station, and the terminal building as well as the existing production.
- Dimensioning of a wind turbine to complement the PV and BESS system for covering the whole electricity consumption at the marina and ferry harbour, including the heat-pump consumption, EV charging and any other expected increases in the electricity consumption.
- A wind turbine will maybe be installed at the ferry harbour, which is 750 m away from the marina (Figure 4). It should be noted, however, that the municipality will invest only if the payback period is less than 20 years.

Since the purchasing price of electricity is higher than the selling price, due to taxes, it is better to consume the produced energy within the parcel than to sell it. The two harbours are on separate parcels, which would have to be joined into one. Furthermore, they would have to be connected by a sea cable (price: 60.000 euro). This may not be feasible, but energy-wise they can be calculated as one parcel.

Roughly speaking, the demand at the ferry harbour is small, while the future production could be large. In the future, years from now, the ferry might become municipal, rather than private. In that case, the ferry would be a large consumer, able to consume the produced energy when docked. It remains to investigate the legal implications of counting the ferry as a part of the parcel, but it would be a desirable scenario from the renewable energy point of view.

Table 2 presents the relevant technology data for small wind turbines under 25 kW. The wind turbine will be grid connected according to the present parcel. In comparison with PV panels, the full load hours are about 1.6 times the corresponding value for PV panels. It means that a 10 kW wind turbine, for instance, would provide as much energy as a PV plant at 16 kW. However, the investment in a wind turbine would be five times higher than that of a PV plant of equal size, leading to a longer payback period.

Table 2. Technology data for a grid connected wind turbine under 25 kW

Parameter	**Value**	**Comment**
Average annual full load hours	1600 h	[3]
Technical lifetime	20 years	[3]
Construction time	1 year	[3]
Space requirements	0.8 square metres per kW	[3]
Specific investment incl. grid connection	6000 EUR/kW	The price is for 5 kW. Prices vary significantly depending on size [3]
Fixed O&M costs	--	[3]
Variable O&M costs	3.8 EUR/MWh	[3]

3.4 Summary of hardware and software components

This scenario includes an investigation about installations of a wind turbine at the harbour. The size is determined by the cash flow analysis. The rest of the equipment in figure 15 is existing equipment. The heat pump and electrical vehicles are to be used for demand response.

The software for the system is to be developed by Route monkey and Vcharge for controlling the demand response.

The following technologies will be provided by the partners Vcharge and Route Monkey: Charging control of the boats and the demand response application

4 Scenario 3, Include the Ballen Village

Since one overall goal for Samsø is to combine the electricity sector with the heating sector, we include the district heating plant in this scenario.

4.1 Current state of technology

Figure 16 shows how the Ballen-Brundby district heating plant supplies the two villages of Ballen and Brundby. For the future, it will be important to know the consequences of adding a large electric heat pump to the plant, as a supplement to the existing straw fired boiler. Furthermore, small heat pumps could be useful in the outer regions of the network.

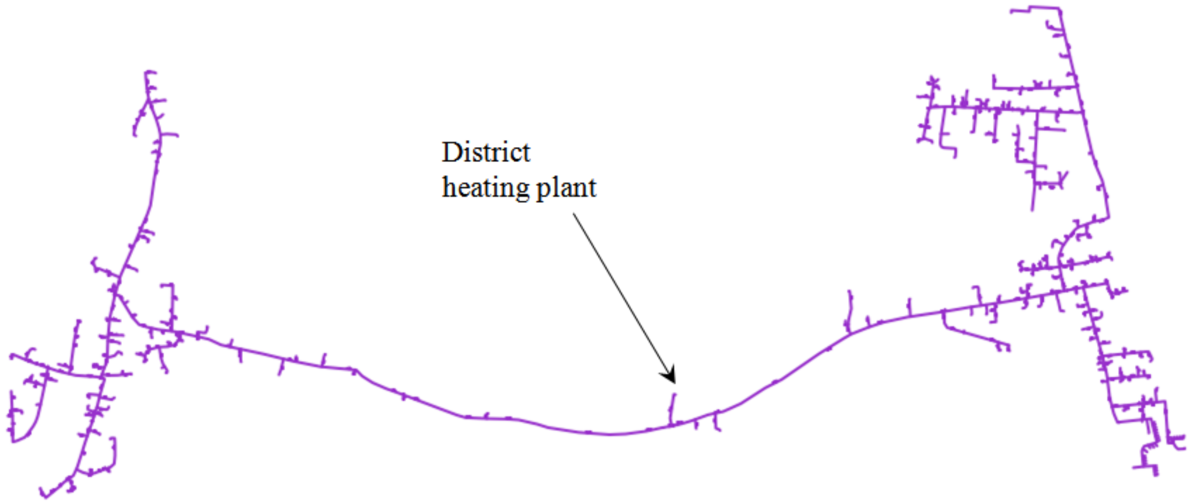

Figure 16. Ballen is on the district heating network. The plant is in the middle, supplying the two villages of Brundby (western cluster) and Ballen (eastern cluster).

Local farmers supply straw, which is burnt in the plant in order to heat up water, which is then transported in a network to 280 consumers, including: private households, hotels, and shops. The district heating plant is owned by the consumers themselves, and decisions concerning its operation are made by a board of voluntary consumers at monthly board meetings. An operator visits the plant once or two times per day, to look after the plant and to feed straw bales onto a conveyor belt. The general assembly makes the long-term decisions, once every year.

The plant size is 1.6 MW, and it consumes about 1600 tonnes of straw plus 2000 litres of oil every year. The network is 7 kilometres long, and it consists of twin pipes, where the feed pipe and the return pipe run together in one cylinder of insulation. The network losses are 30%, and the annual demand from the consumers, excluding network losses, is 4000 MWh. A private consumer pays a fixed annual fee (760 EUR/year including 25% VAT) and a variable price for the heat (102 EUR/MWh including 25% VAT).

4.2 Sample recruitment

The demonstrator is organized by the Samsø partners, that is, the municipality (SK), Samsø Energy Academy (SE) and Samsø Elektro (SEL). The board of the district heating power plant, the general assembly, and the straw suppliers have to be involved in this scenario as well.

4.3 Main tasks

In this scenario the following research goals are to be considered:

- Determination of size of heat pumps depending on different case studies. The heat consumption for all the cases will be analysed and the size of the heat pump determined accordingly. The following cases are under consideration.
    - A small booster heat pump connected to the district heating system, which should increase the feed temperature in the farther branches of the district heating network (north and south).
    - A small heat pump to improve the delta-T in the marina. This heat pump could be behind the meter at the marina.
    - A heat pump inside the district heating plant, in order to analyse replacement of the biomass used for heating with electricity for the heat pump. This heat pump will be fed with electricity from outside the marina.
- Development of demand side management control of the heat-pumps according to produced electrical power from the PVs and wind turbine and peak-shaving for the loads as well, taking the actual thermal demand into account.

Hourly production data from the plant are not available, but proxy data can be used instead. The heat production is correlated to the number of heating degree days. Therefore outdoor temperature measurements can be used as proxy data. Main parameters include plant output [kW], water flow [cubic metres per hour], and the temperatures of the outgoing feed flow and the incoming return flow [centigrade]. However, to collect data on an hourly basis is infeasible, because it would require a new operator panel inside the plant and some reprogramming, in order to store data on a memory device.

Outdoor temperature measurements are available; see the example in Figure 17. As an approximation the consumed heat energy is proportional to the number of degree days, which can be deduced from the temperature data. An approximation is not accurate, obviously, but it may be accurate enough, in consideration of other uncertainties that occur in the model.

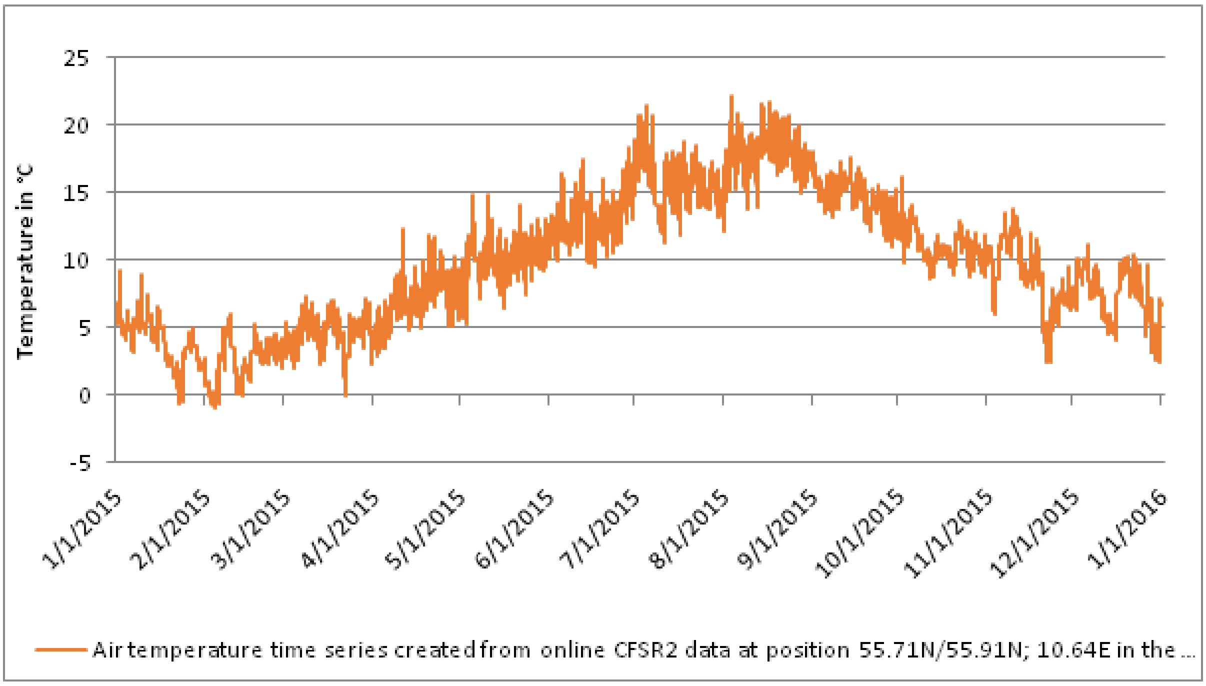

Figure 17. Temperature variation on Samsø in 2015 (satellite based data from CSFR).

A compression heat pump uses electricity to convert renewable energy into usable energy. It draws on a heat reservoir to heat up water or air. It is in agreement with the Samsø energy plan to install a large heat pump in the district heating plant, and replace straw by electricity. However, there is no natural heat reservoir of sufficient temperature to supply the heat pump; if the input temperature is low, such as earth temperature (8.7 degrees average), and the desired output temperature is 90 degrees, then the efficiency would be unacceptably low. A solution is to keep the straw based heating plant, but replace some of its thermal work by a heat pump using the hot chimney flue as heat reservoir. The heat pump would preheat the return water from 45 degrees to, say, 65 degrees, and the straw furnace could supply the remainder up to 90 degrees boiler temperature.

The heat pump would save straw, and it depends on prices and efficiencies whether the savings can outbalance the investment within a reasonable period of years. Table 3 provides technology data for heat pumps. The table is sufficient to make a first calculation of such an investment's viability.

Table 3. Technology data for a compression heat pump less than 4 MW.

Parameter	Value	Comment
Existing plant size Ballen-Brundby	1.6 MW,th	
Existing production	4000 MWh,th/yr	Max 5500 MWh,th/yr
Current annual fuel consumption	1600 tonnes of straw + 2000 litres of oil	
Price of straw	0.11 EUR/kg	Depends on the time of year and the moisture content
Technical lifetime of a heat pump	25 years	[3]
Annual average efficiency	360%	As high as 900 with higher supply temperature and lower

		output temperature [3]
Space requirements	20 square metres per MW,th	[3]
Electricity consumption for pumps etc. in percent of heat output	9%	[3]
Specific investment	660 000 EUR/MW,th	[3]
- Included equipment is	50%	[3]
- Included installation is	50%	[3]
Fixed O&M costs	2000 EUR/(MW,th·yr)	[3]
Variable O&M costs	8.2 EUR/MWh,th	[3]
- included electricity costs are	6.4 EUR/MWh,th	[3]
- included other O&M costs are	1.8 EUR/MWh,th	[3]

4.4 Cash flow analysis of a supplementary heat pump

The district heating plant buys electricity at a price, which is extraordinarily low. Furthermore, the straw combustion produces waste heat at a very high temperature. A supplementary heat pump, connected to the chimney, could thus have a good efficiency (Coefficient of Performance, COP) and at the same time operate at a low cost. The question is whether the savings in straw purchase could pay for the investment.

Figure 18 shows a cash flow analysis with a 500 kW heat pump, which covers about half of the heat production in the plant. It is clearly a good investment; the payback period is eight years compared to the lifetime of 25 years of the heat pump. However, the existing boiler may not last that long, even if the heat pump prolongs its life.

The consumers pay a fixed amount and a variable amount for the heat. Ideally, the variable income to the company should match the variable costs of producing heat. The cost price, which is the direct, variable cost of producing one unit of heat, is of interest to the district heating company. Figure 19 shows that the direct cost drops immediately at the beginning of the investment, even though the project is financed through a loan. The consumers will thus experience a reduction in the variable price immediately. The reduction is more than 20% according to the simulation. It is apparently a viable investment.

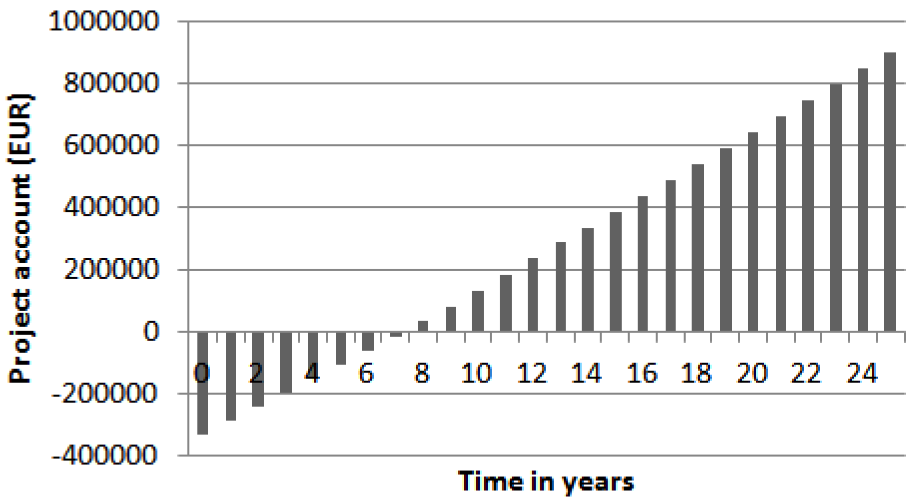

Figure 18. Project account. Investment in a supplementary heat pump of 500 kW,th in the district heating plant, standard case.

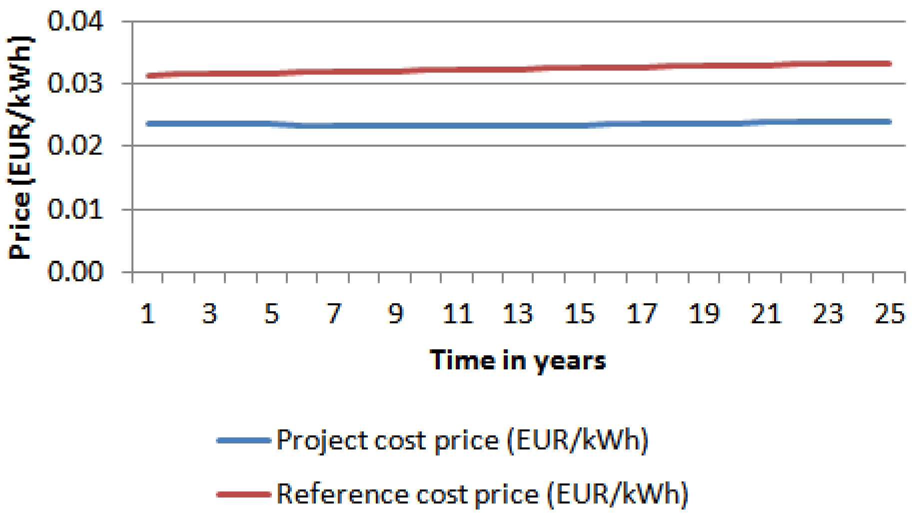

Figure 19. Direct cost of producing one unit of heat, before and after installing a supplementary heat pump.

Again, the calculations rest on some assumptions and the simulations contain three cases, which reflect certain choices of the parameters: 1) best case, 2) standard case, and 3) worst case. The following list describes the main assumptions.

- The rated power of the heat pump (HP) can be chosen freely, and adjusted to achieve a specific goal, such as a desired mix between heat pump and straw boiler.
- The lifetime of the HP is assumed to be 25 years, but the remaining lifetime of the straw boiler is probably less.
- We assume that the HP acquires its heat energy from the chimney; that will result in a very high COP.
- Technological data are from an official Danish catalogue ([2, 3]).

- The full load operating time, the duty cycle, is theoretically between 0% and 100%; we assume 75% in the standard case (personal guess).
- The electricity price is the marginal price, that is, the price of the last saved kilowatt-hour, disregarding subscription fee.
- The electricity price will most likely grow, but we include a very cautious growth rate (such as ¼ of a percent per year). It can be adjusted.
- The price of straw depends on the season; it is cheaper immediately after harvest. Historical prices have been growing. An annual growth rate is included in the calculations.
- Project interest rate, inflation, and discounting are omitted, to favour transparency over accuracy.
- The investment is financed through a loan. The loan is from the Danish municipal fund, at a low interest rate, plus a one percent risk premium to the municipality for guaranteeing the loan. The loan runs for 10 years, which is acceptable for a district heating company (not too long, not too short).

The worst case and best case scenarios help to give an idea of the extremes of solutions (the envelope).

It is necessary to investigate the case in more detail, but these preliminary results indicate that it is worth probing deeper into the design of a heat pump that supplements the existing straw boiler. The results will be presented to the board of Ballen-Brundby district heating company for further decisions. The next step would be to pay an engineering company to perform a feasibility study.

4.5 Summary of hardware and software components

This scenario includes an investigation of a heat pump at the heating plant, to be financed by the district heating company. The rest of the equipment for this scenario is as in scenario 2 or already existing equipment. The heat pump and electrical vehicles are to be used for demand response.

5 Scenario 4, Include the Whole Island

Partner AAU/PLAN will make a simulation of the whole island (in WP8). It will be on an overall level, where, for instance, all 21 wind turbines are lumped into one, and all four district heating plants are lumped into one. The simulation model can be used to make what-if analyses of various future policies.

5.1 Sample recruitment

The existing system is analysed for the purpose of creating primarily a reference system and secondarily making further short term scenarios with increased renewable energy. The task leader is Aalborg University (AAU/PLAN).

5.2 Main tasks

In this scenario the following research questions are to be considered.

- What is the current import/export status, and how would it change with the Scenarios 1-3?
- How do changes, at the marina for instance, affect the whole island?
- What are the consequences of introducing more BESS systems on Samsø?
- Is it better to have a centralised BESS system rather than individual systems in the households?
- What are the consequences if the wind turbines are not renewed?
- How much PV power would be necessary in order to substitute an existing 1 MW wind turbine considering the difference in the production profiles?
- What are the consequences of installing supplementary heat pumps in one or several district heating plants?

Figure 20 shows the interrelations that are considered for the scenario. Although the model uses a simplified energy system, it illustrates the dependencies of the following sectors on Samsø: fuels, productions, balancing and consumption.

Further to the electricity demand, the demand for transportation, heating and industry are also included. The heat demand is simulated hour-by-hour depending on outside temperature measurements and annual heat demands taken from the energy balance, while transport and industry is based solely on the annual energy balance.

The technological changes of the Ballen marina, the ferry harbour or the whole town are investigated through their scenarios on the island's whole energy system. This simulation can be done by having the additional technologies as part of the whole energy system, or as a closed-off layer of improving a local marina, before surplus and deficit are balanced by the grid.

The various demands are analysed with the energy system simulation model EnergyPLAN. It simulates each sector on an hourly basis over a one-year time horizon. This makes modeling of intermittent energies possible, such as wind and solar, and simulates their effect on the rest of the energy system. First, a reference model of the existing energy system is simulated based on a thorough study, thereafter, the technological changes suggested for the Ballen marina are analyzed.

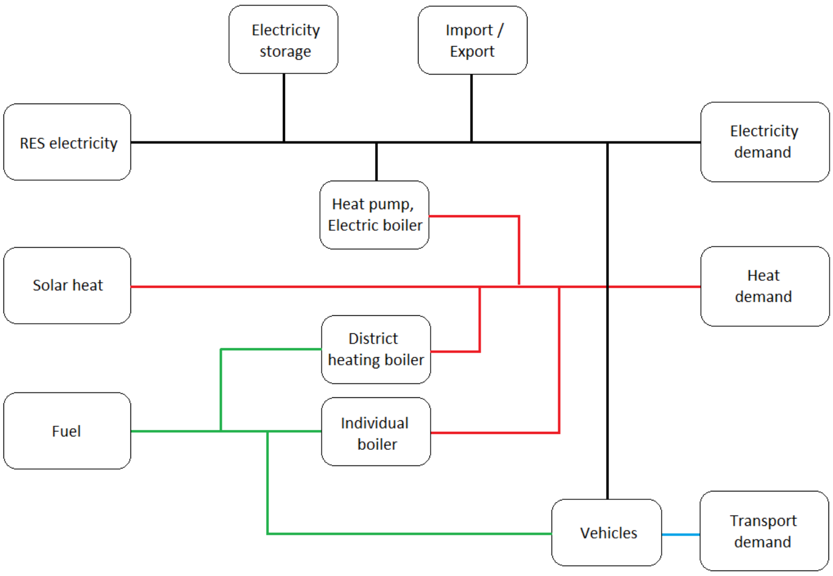

Figure 20. Simplified energy system in EnergyPlan.

5.3 Summary of hardware and software components

The software package EnergyPlan[2] simulates the operation of energy systems on an hourly basis, including the electricity, heating and cooling, industry, and transport sectors.

One of the key objectives is to aid in the design of a smart energy system, which combines the electricity sector with the heating sector by means of thermal storages and heat pumps.

[2] http://www.energyplan.eu/

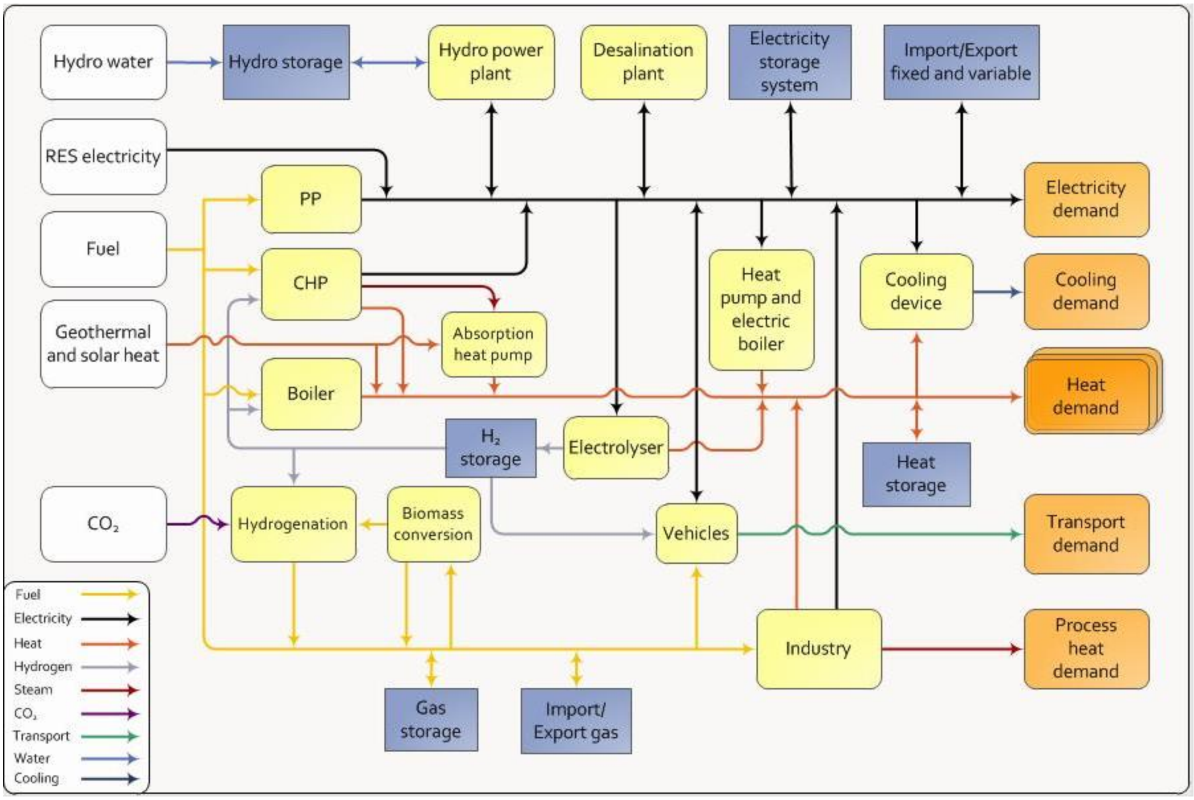

Figure 21. A generic energy system in EnergyPLAN. Different sectors can be combined by means of components that interact with storages. The software optimises the operation of the energy system as opposed to optimising the investments.

6 Discussion and Conclusions

As mentioned in the Introduction section, the scope of the current deliverable (D3.1) is to make a technical overview of the Samsø demonstrator. Since we have four scenarios, the task is rather large. This is due to many practical constraints, especially space limitations combined with legal constraints. Generally speaking, the marina has a high consumption and space is scarce, while the ferry harbour has a low consumption and ample space. This may change in the coming years, however.

6.1 Risk Mitigation Plan

The Samsø partners have identified four main *challenges*, listed in the following bullets:

- The Samsø municipality will invest in renewable energy devices *only* if the investment is economically viable.
- If a consumer wishes to withdraw from the Ballen-Brundby district heating contract, the consumer must pay a significant exit fee.
- Citizens and tourist actors will likely object to technical installations that obstruct the view to the horizon, are in motion, make noise, or consume parking space.
- Electrical flow out of a cadastral parcel, beyond the electricity meter, will be taxed heavily.

The four challenges could create deviations from the six *specific* objectives previously mentioned. Table 4 treats the specific objectives in detail, one-by-one. The main action is to include the ferry harbour, because the marina is sensitive to opposition from the citizens. The ferry harbour is industrial, and less sensitive in the public eye. The two sites are on separate parcels, however, within a line-of-sight distance of 750 meters. The price of a connecting sea cable would be about 60.000 euro.

The wind turbine at the end of the marina pier has been rejected owing to non-technical barriers. The general public opinion of wind turbines is mixed. There is a risk of a loss of income, in case boat owners avoid the harbour; there is a risk that even a small wind turbine could damage the fine reputation that the marina enjoys presently. As a substitute, there is an effort to find enough space in order to double the size of the PV plant.

The municipality is evaluating the installation costs in detail, taking into account the main ideas of the project.

Table 4. Current evaluation of specific objectives.

Specific objective	Evaluation	Counter-measure in case of failure (Plan B)
1. PV panels	Likely. Minimum size 30 kW. The size depends on the available space.	(Installation of battery and PV panels in another location.)
2. Wind turbine at the end of the pier	Rejected. A wind turbine on the marina generates objections from the citizens, the politicians, and the visiting boat owners. Power from the grid is largely wind turbine electricity already.	Extension of the PV plant from 30 kW to 60 kW.

3. EV charging station installed at the marina	Rejected, it is economically unviable.	Inclusion instead of the existing 22 kW EV charging station, containing two plugs, at the ferry harbour.
4. Replace district heating with electricity in the service building	Rejected, the district heating is already renewable energy.	First option is to install a heat pump in the harbour master's office. Second option is to include the existing heat pump in the ferry harbour. Third option is that the district heating company installs a (large) heat pump at the plant, in order to preheat the water, which carries heat to the consumers. This third option would have to be done only via simulations during the project period, since the district heating company is bound by a contract with the farmers for straw until 2022.
5. BESS system at marina	Likely	
6. New market model	Likely. The market model will be set up for the boat charging and a demand response model is to be set up in WP5.	
7. Customer acceptance	Likely. Meetings and questionnaires will be used to inform customers about the project ideas and get their point of view.	

6.2 Next Steps

Deliverable D3.1 analyses the various scenarios and it provides technical ideas for the design. Data has been procured by the Samsø partners in order for other SMILE partners to continue with their calculations or simulations. The following list gives an overview of the next steps.

- Create a formal, municipal case regarding Scenario 1, and present it to the municipal council in January 2018. Try to get their approval.
- Hear the citizens, if they have objections or proposals.
- Write technical specifications suitable for an invitation to tender (deliverable D3.3).
- The municipality invites craftsmen to tender, and selects a company that can implement the project.
- Present the cash flow analysis of the supplementary heat pump to the district heating company. Try to obtain their funding for a feasibility study.

It is clear that some decisions are beyond our control, and some of the municipal decisions will take time.

Table 5 shows all tasks in WP3. The current deliverable is input to the task concerning the installation of heat pumps (T3.3), the installation of the battery (T3.4), and the installation of the PV plant (T3.5).

Furthermore, the data will be used for the technical models and analyses (WP5), particularly the task on storage integration (T5.4), and the task on real-time simulation with hardware in the loop test (T5.7). Furthermore, the data will be used in the work package concerning socio-economic studies (WP6), particularly the tasks on indicators (T6.1), life cycle assessment (T6.2), and cost/benefit analysis (T6.4). Furthermore, the data will be used in the work package concerning impact analyses (WP8), particularly the tasks concerning energy models (T8.1) and high-RES scenarios (T8.2).

In order to provide a summary, Table 6 shows what has been decided, and the possible ranges of solutions. The sizes are within a range, because the final decisions depend on the municipal council and citizens, whom are yet to be approached.

Table 5. Tasks in work package 3.

Task	Title	Leader	Start	End	Status
T3.1	Case study specification	SE	May 17	Oct 17	100%
T3.2	Citizens interaction	SE	May 17	Apr 20	10%
T3.3	Installation of heat-pumps or other	SK	Aug 17	Jun 18	
T3.4	Installation of battery	DTI	Aug 17	Jul 18	
T3.5	Installation of PV and wind turbine	SK	Aug 17	Apr 19	
T3.6	Demand response evaluation	AAU	Apr 18	Apr 20	
T3.7	Overall control	AAU	Apr 18	Feb 21	

Table 6. Decision table corresponding to the specific objectives (Table 1).

Specific objective	Minimal case	Maximal case
1. PV panels	30 kW	60 kW
2. Wind turbine at the end of the pier	0 kW	34 kW, the wind turbine electricity already in the grid.
3. EV charging station installed at the marina	0 kW	22 kW at the ferry harbour.
4. Replace district heating by electricity in the service building	Install a small heat pump in the harbour master's office.	0.5 – 1 MW in the district heating plant. In simulation.
5. BESS system at marina	240 kWh	240 kWh
6. New market model	A prototype	All plugs in the marina
7. Customer acceptance	Prototype users	All stakeholders

6.3 Conclusions

In summary the Samsø demonstrator is composed of four scenarios. The scenarios will study, and partially implement, the following ideas: the design of an experimental smart energy system in the Ballen marina, the increase of the self-consumption of PV electricity by means of a BESS, the control of the charging of boats under the constraints of the local network and the available renewable energy, and the combination of the electricity sector with the heating sector by means of heat pumps.

Scenario 1. The scenario concerns the Ballen marina. An array of PV panels will be installed and connected to a BESS. Cash flow simulations indicate a payback period of nine years, which makes it an economically viable investment for the municipality. The BESS is financed by the SMILE project and the PV panels by a loan. There are more than 200 electrical sockets for the visiting boats to charge their batteries. Presently boats generally connect as soon as they arrive, but with the smart energy system they do not necessarily receive electricity immediately. A demand side management system will provide electricity to the boats in quanta, rather than continuously, in order to keep the power amplitude within certain constraints. Thus, the municipality may be able to postpone an investment in a stronger electric network on the harbour. Boat owners may opt to use a conventional socket, with continuous power, but at a higher price per kilowatt-hour. The harbour master's office will be equipped with a heat pump in order to increase the use of renewable energy. The marina is within a single cadastral parcel, and a single meter (a smart meter) measures the total consumption. The harbour can be seen as an experimental smart energy system. It is possible to make experiments to a certain extent. As an example, the impact of the BESS could be measured with the following procedure: (1) disconnect the BESS, (2) perform measurements in particular points on the marina, (3) reconnect the BESS, (4) perform the same measurements again, and (5) compare values. Measurements of interest could be the amount of PV self-consumption or the voltage level at the sockets.

Scenario 2. The scenario includes the ferry harbour. The ferry harbour is an industrial harbour and sailing boats are not allowed. Contrary to the marina, the ferry harbour has ample space, and it is possible to install a wind turbine there, economy permitting. The ferry harbour has already a PV plant, electric vehicle chargers, and a heat pump. However, the electric consumption is small compared to the marina, and excess renewable energy must be sold to the grid. The selling price is much lower than the buying price, which makes it difficult to create a viable business case. The municipality will not invest if the payback period is more than 20 years. Nevertheless, the renewable energy can be included in the energy balance of the Ballen village.

Scenario 3. The scenario includes all of Ballen village. Almost the entire Ballen village is connected to a district heating network, which is driven by a straw burning plant (renewable energy). It is unlikely that the district heating company will install new heat pumps within the course of the SMILE project, but SMILE will provide calculations and simulations in order to support such a decision. It is suggested to install a supplementary heat pump inside the district heating plant. The heat reservoir is the exhaust chimney, and the objective is to preheat the water before it enters the straw boiler. The heat pump thus works at a high input temperature, and the output temperature is feasible for a heat pump (65° C). The heat pump will thus operate with a high efficiency. The cash flow analysis indicates a payback period of seven years. A short loan with a maturity of ten years finances the project. Despite the loan, the unit cost of produced heat is immediately lowered by the heat pump. Therefore the scenario will be presented to the board of the district heating company as soon as possible.

Scenario 4. The scenario includes the whole island. The present energy system is modelled in a software package in order to analyse various future scenarios. Although the model uses a simplified energy system, it illustrates the dependencies of the following sectors on Samsø: fuels, productions, balancing, and consumption. The objective is to aid in the design of an island-wide smart energy system, which combines the electricity sector with the heating sector by means of thermal storages and heat pumps. The simulations will result in recommendations for policymakers.

At this point it is possible to foresee some positive consequences of the SMILE project. The BESS will make the PV installation economically viable for the municipality. Consequently, the share of renewable energy will increase. Furthermore, the marina will most likely obtain a billing system, where the boat owners are billed according to their actual electricity consumption. On a longer term, the district heating consumers may enjoy lower heat prices after an investment in a supplementary heat pump at the heating plant. Naturally, positive experiences may instigate further investments elsewhere on the island. The ultimate objective is to attract more settlers.

Acknowledgement

The maps contain GeoDanmark-data from 'Styrelsen for Dataforsyning og Effektivisering' and the Danish municipalities, Sep 2017. They are published in accordance with the conditions for use in http://www.geodanmark.dk/brugeradgang/vilkaar-for-data-anvendelse/

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8 Appendix A. Cash flow analysis of a PV plant, Scenario 1

	PV panels + grid connected wind turbine, Ballen, Samso						
	Jan Jantzen	jj@energiakademiet.dk					
	The SMILE project	www.h2020smile.eu					
	Input fields are in green						
	English language and EUR (0 or 1)?		1	0.133333	Exchange rate		
	Currency		EUR				
	Best, baseline or worst case?		2		1	2	3
Notes	**Parameters**		**Reference: Do nothing**	**Project: PBW**	**Best case**	**Standard case**	**Worst case**
	Lifetime (yr)		30	30			
	Battery lifetime (yr)			15	18	15	14
	Annual demand in harbour (kWh)		105000	105000	126000	105000	99750
1	PV size (kWp)			30			
2	PV required space (sqm)			187.5			
3	PV investment (EUR)		0.00	42000	31500	42000	52500
	Including PV inverter (EUR)			9000			
4	PV full load hours (kWh/kWp)			1030	1081	1030	978
5	PV production (kWh/yr)			30888			
6	Electricity buying price (EUR/kWh)		0.21	0.21	0.22	0.21	0.20
7	Electricity selling price (EUR/kWh)			0.03	0.03	0.03	0.02
8	Electricity prices growth rate		0.25%	0.25%	0.50%	0.25%	0.00%
9	PV degradation rate due to age			0.63%			
	WT size (kW)			0			
	WT lifetime (yr)			20	25	20	17
	WT full load hours (kWh/kWp)			1280	1408	1280	1152
	WT production (kWh/yr)			0			
	WT investment (EUR)			0	0	0	0
	WT O&M costs (EUR/yr)			0			
10	Project account interest rate		0.00%				
	Inflation rate		0.00%				
11	Real interest rate		0.00%				
12	Risk premium		0.00%				
13	Discount rate		0.00%				
	Tax rate		0%				
	Loan		42000				
14	Interest rate		1.61%				
	Maturity		25				
	Annual installment (EUR)		2054				

			Year													
Notes		Total	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
			0	1	2	3	4	5	6	7	8	9	10	11	12	13
	INCOME STATEMENT															
	Reference: Do nothing															
	Consumption (kWh)	**-3150000**		-105000	-105000	-105000	-105000	-105000	-105000	-105000	-105000	-105000	-105000	-105000	-105000	-105000
	Purchase from grid (EUR)	**-685580**		-22035	-22090	-22145	-22201	-22256	-22312	-22368	-22423	-22480	-22536	-22592	-22649	-22705
	Income (EUR)			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Reference cash flows (EUR)	**-685580**	0	-22035	-22090	-22145	-22201	-22256	-22312	-22368	-22423	-22480	-22536	-22592	-22649	-22705
	Ref. electricity price (EUR/kWh)	**0.22**														
	Discount factors (EUR)		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Project: PBW															
9	PV degradation factor			1.00	1.00	0.99	0.99	0.98	0.97	0.97	0.96	0.96	0.95	0.94	0.94	0.93
	PV production (kWh)			30888	30888	30693	30499	30304	30110	29915	29720	29526	29331	29137	28942	28747
	Relative capacity = PV production/Load			29%	29%	29%	29%	29%	29%	28%	28%	28%	28%	28%	28%	27%
15	Self consumption fraction without battery			73%	73%	73%	73%	73%	73%	73%	73%	74%	74%	74%	74%	74%
	Remainder = PV - demand (kWh)			-74112	-74112	-74307	-74501	-74696	-74890	-75085	-75280	-75474	-75669	-75863	-76058	-76253
16	Energy from grid (kWh)	**-2601161**	83%	-74155	-74155	-74335	-74516	-74698	-74879	-75061	-75244	-75426	-75609	-75792	-75976	-76160
	Energy to grid (kWh)	**298796**		43	43	29	15	2	-11	-24	-36	-48	-60	-71	-82	-93
	Balance check (kWh)			0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
17	PV production to own consumption			100%	100%	99%	97%	96%	95%	94%	93%	92%	90%	89%	88%	87%
	Expenses (EUR)															
2	PV operation and maintenance (EUR)			-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375
18	Battery operation and maintenance (EUR)			-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375
	Purchase from grid (EUR)	**-567570**		-15562	-15601	-15678	-15755	-15833	-15911	-15990	-16069	-16148	-16228	-16308	-16388	-16469
	Tax (EUR)	**0.00**		0	0	0	0	0	0	0	0	0	0	0	0	0
	Debt interest (EUR)	**-9351**		-676	-654	-631	-609	-585	-562	-538	-513	-488	-463	-438	-412	-385
19	Replacement inverter (EUR)			0	0	0	0	0	0	0	0	0	0	0	0	-9000
	WT operation and maintenance (EUR)			0	0	0	0	0	0	0	0	0	0	0	0	0
	Income (EUR)															
20	PV sales to grid (EUR)	**8438**		1	1	1	0	0	0	-1	-1	-1	-2	-2	-2	-3
	WT sales to grid (EUR)			0	0	0	0	0	0	0	0	0	0	0	0	0
	Project cash flows (EUR)	**-608983**		-16987	-17004	-17059	-17114	-17168	-17223	-17278	-17333	-17388	-17443	-17497	-17552	-26606
	Proj. electricity price (EUR/kWh)	**0.19**														
	Net savings (EUR)	**76597**		5048	5086	5087	5087	5088	5088	5089	5090	5092	5093	5095	5097	-3901
	CASH FLOW STATEMENT															
	Investment															
	PV investment (EUR)		-42000													
	WT investment incl grid connection (EUR)		0													
	Financing															
	Remaining debt (EUR)		42000	40622	39222	37800	36354	34885	33393	31877	30336	28770	27179	25563	23920	22252
	Fixed payment (EUR)			-2054	-2054	-2054	-2054	-2054	-2054	-2054	-2054	-2054	-2054	-2054	-2054	-2054
	Interest (EUR)			-676	-654	-631	-609	-585	-562	-538	-513	-488	-463	-438	-412	-385
	Principal repayment (EUR)			-1378	-1400	-1423	-1445	-1469	-1492	-1516	-1541	-1566	-1591	-1616	-1642	-1669
	Net cash flow	**34597**	-42000	5048	5086	5087	5087	5088	5088	5089	5090	5092	5093	5095	5097	-3901
	Discounted net cash flow		-42000	5048	5086	5087	5087	5088	5088	5089	5090	5092	5093	5095	5097	-3901
21	Internal rate of return IRR(levetid)	8.1%		#NUM!	#NUM!	#NUM!	-23.8%	-14.7%	-8.4%	-4.0%	-0.7%	1.7%	3.6%	5.1%	6.3%	5.4%
	Project account															
22	Cumulative net savings (EUR)		-42000	-36952	-31866	-26779	-21692	-16604	-11516	-6426	-1336	3756	8849	13944	19041	15139
23	Cum. discounted net savings (EUR)	34597	-42000	-36952	-31866	-26779	-21692	-16604	-11516	-6426	-1336	3756	8849	13944	19041	15139

2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048
14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
-105000	-105000	-105000	-105000	-105000	-105000	-105000	-105000	-105000	-105000	-105000	-105000	-105000	-105000	-105000	-105000	-105000
-22762	-22819	-22876	-22933	-22990	-23048	-23105	-23163	-23221	-23279	-23337	-23396	-23454	-23513	-23572	-23631	-23690
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-22762	-22819	-22876	-22933	-22990	-23048	-23105	-23163	-23221	-23279	-23337	-23396	-23454	-23513	-23572	-23631	-23690
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.92	0.92	0.91	0.91	0.90	0.89	0.89	0.88	0.87	0.87	0.86	0.86	0.85	0.84	0.84	0.83	0.82
28553	28358	28164	27969	27774	27580	27385	27191	26996	26802	26607	26412	26218	26023	25829	25634	25439
27%	27%	27%	27%	26%	26%	26%	26%	26%	26%	25%	25%	25%	25%	25%	24%	24%
74%	74%	75%	75%	75%	75%	75%	75%	76%	76%	76%	76%	76%	76%	76%	77%	77%
-76447	-76642	-76836	-77031	-77226	-77420	-77615	-77809	-78004	-78198	-78393	-78588	-78782	-78977	-79171	-79366	-79561
-76344	-76529	-97446	-97550	-97653	-97756	-97858	-97959	-98059	-98159	-98258	-98356	-98454	-98550	-98647	-98742	-98837
-103	-113	20609	20519	20428	20336	20243	20149	20055	19960	19865	19768	19671	19574	19475	19376	19276
0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
86%	85%	22%	22%	21%	21%	21%	20%	20%	19%	19%	18%	18%	18%	17%	17%	16%
-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375
-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375	-375
-16550	-16631	-21230	-21306	-21382	-21458	-21534	-21610	-21686	-21762	-21839	-21915	-21992	-22069	-22145	-22222	-22299
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-358	-331	-303	-275	-246	-217	-188	-158	-127	-96	-65	-33	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	-9000	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-3	-3	572	571	570	569	567	566	565	564	562	561	560	558	557	555	554
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-17661	-17715	-21711	-21760	-21808	-21856	-21904	-21951	-21998	-22045	-22091	-22137	-31182	-22260	-22338	-22417	-22495
5101	5103	1165	1173	1182	1192	1201	1212	1223	1234	1246	1259	-7728	1253	1233	1214	1195

Notes	
1	Rated max power output from all PV panels
2	Energinet: Technology Data
3	Includes panels, inverter, and mounting (SEL)
4	Annual production in equivalent number of hours running at full capacity, higher than normal in Samso. Bearing is 22 deg toward east.
5	Nominal production, factor 1020 kWh/kW is normal for Samsø
6	Differential price from grid (disregarding subscription fees), savings
7	Selling overflow energy to grid
8	If zero, the growth rate of the electricity price is assumed equal to the inflation rate
9	All panels degrade over time, Scheuten guarantees a better production than 0.63% linearly from year three
10	Market interest rate
11	Interest rate cleaned from inflation
12	Affects the discount rate
13	Discount rate should be greater than or equal to real interest rate
14	kommunekredit.dk, 6 Sep 2017
15	Exponential decay with 15% self consumption at 42% nominal coverage
16	The formula interpolates AAU's results.
17	Capacity factor of the PV yield, the higher the better.
18	Guess work, no references
19	The inverter lasts only 10-15 years
20	Sell overflow to the grid
21	Undefined the first few years due to the IRR algorithm
22	Does not consider interest
23	Uses discount factor which may be different from market interest

9 Appendix B. Cash flow analysis of a supplementary heat pump, Scenario 3

	SMILE large heat pump, Ballen-Brundby, Samso					
	Jan Jantzen (jj@energiakademiet.dk)					
	Input fields are in green					
	Prices in EUR (0 or 1)?	1	0.1333333	Exchange rate		
	Currency	EUR				
	Best, standard or worst case?	2		1	2	3
Notes	**Parameters**	**Reference: Do nothing**	**Project: HP**	**Best case**	**Standard case**	**Worst case**
	Lifetime (yr)	25	25			
	Annual production (kWh heat)	5600000	5600000	5040000	5600000	6440000
1	HP size (kW heat)		500			
2	HP required space (sqm)		10			
2	HP investment (EUR)	0.00	330000	313500	330000	379500
3	COP (kWh heat/kWh electric)		6.0	7.5	6.0	5.0
	HP annual duty cycle ()			0.80	0.75	0.50
	HP hours of operation (h/yr)			7008	6570	4380
4	HP production (kWh heat/yr)		3285000	3504000	3285000	2190000
	HP electricity consumption (kWh electric/yr)		547500			
5	Electricity buying price (EUR/kWh)	0.09	0.09	0.08	0.09	0.09
6	Electricity prices growth rate	0.25%	0.25%	0.00%	0.25%	0.50%
7	Plant heat yield (kWh heat/kg straw)	3.4				
8	Annual straw consumption (kg)	1647059	680882			
	Straw boilers share (%)	100%	41%			
	Calorific value of straw (kWh/kg)	3.5	3.5			
	Straw price (EUR/kg)	0.11	0.11	0.11	0.11	0.10
9	Straw price growth rate (%/yr)	0.25%	0.25%	0.50%	0.25%	0.00%
10	Project account interest rate	0.00%				
	Inflation rate	0.00%				
11	Real interest rate	0.00%				
12	Risk premium	0.00%				
13	Discount rate	0.00%				
	Tax rate	0%				
14	Loan	330000				
15	Interest rate	1.69%				
	Maturity	10				
	Fixed payment (EUR)	36144				

Notes		Total	Year 2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
			0	1	2	3	4	5	6	7	8	9	10	11	12	13
	INCOME STATEMENT															
	Reference: Do nothing															
	Energy production (kWh/yr)	**140000000**		5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000
	Straw buying price (EUR/kg)			0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
	Straw consumption (kg)	**41176471**		1647059	1647059	1647059	1647059	1647059	1647059	1647059	1647059	1647059	1647059	1647059	1647059	1647059
	Straw energy (kWh/yr)			5764706	5764706	5764706	5764706	5764706	5764706	5764706	5764706	5764706	5764706	5764706	5764706	5764706
	Purchase of straw (EUR)			-176125	-176566	-177007	-177450	-177893	-178338	-178784	-179231	-179679	-180128	-180578	-181030	-181483
	Reference cash flows (EUR)	**-4537798**	0	-176125	-176566	-177007	-177450	-177893	-178338	-178784	-179231	-179679	-180128	-180578	-181030	-181483
	Reference cost price (EUR/kWh	**0.03**		0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	Discount factors (EUR)		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Project: HP															
	Energy production (kWh/yr)	**140000000**		5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000
	Electricity buying price (EUR/kWh)			0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
	Straw consumption (kg)	**17022059**		680882	680882	680882	680882	680882	680882	680882	680882	680882	680882	680882	680882	680882
	Straw energy (kWh/yr)	**59577206**		2383088	2383088	2383088	2383088	2383088	2383088	2383088	2383088	2383088	2383088	2383088	2383088	2383088
	HP electricity consumption (kWh/yr)			547500	547500	547500	547500	547500	547500	547500	547500	547500	547500	547500	547500	547500
	Total energy consumption (kW	**73264706**		2930588	2930588	2930588	2930588	2930588	2930588	2930588	2930588	2930588	2930588	2930588	2930588	2930588
	Expenses (EUR)															
	Purchase of straw (EUR)	**-1875893**		-72809	-72991	-73174	-73356	-73540	-73724	-73908	-74093	-74278	-74464	-74650	-74836	-75024
	Investment (EUR)		-330000	0	0	0	0	0	0	0	0	0	0	0	0	0
2	HP O&M fixed (EUR)			-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000
2	HP O&M variable (EUR)			0	0	0	0	0	0	0	0	0	0	0	0	0
	HP electricity purchase (EUR)			-47569	-47688	-47807	-47926	-48046	-48166	-48287	-48407	-48528	-48650	-48771	-48893	-49015
	Loan interest (EUR)	**-31444**		-5577	-5060	-4535	-4001	-3458	-2905	-2344	-1772	-1191	-601	0	0	0
	Project cash flows (EUR)	**-3487923**	-330000	-126955	-126739	-126515	-126284	-126044	-125795	-125538	-125272	-124998	-124714	-124421	-124730	-125039
	Project cost price (EUR/kWh)	**0.02**		0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	Net savings (EUR)	**1049875**	-330000	49171	49827	50492	51166	51850	52543	53246	53958	54681	55414	56157	56300	56443
	CASH FLOW STATEMENT															
	Investment															
	HP investment (EUR)		-330000													
	Financing															
	Remaining debt (EUR)		330000	299433	268349	236739	204596	171909	138670	104869	70497	35544	0	0	0	0
	Fixed payment (EUR)			-36144	-36144	-36144	-36144	-36144	-36144	-36144	-36144	-36144	-36144	0	0	0
	Interest (EUR)			-5577	-5060	-4535	-4001	-3458	-2905	-2344	-1772	-1191	-601	0	0	0
	Principal repayment (EUR)			-30567	-31084	-31609	-32144	-32687	-33239	-33801	-34372	-34953	-35544	0	0	0
	Net cash flow	**1049875**	-330000	49171	49827	50492	51166	51850	52543	53246	53958	54681	55414	56157	56300	56443
	Discounted net cash flow		-330000	49171	49827	50492	51166	51850	52543	53246	53958	54681	55414	56157	56300	56443
16	Internal rate of return IRR with	**15.5%**		#NUM!	#NUM!	-31.0%	-17.2%	-8.2%	-2.2%	2.1%	5.1%	7.4%	9.1%	10.5%	11.5%	12.3%
	Project account															
17	Present worth (EUR)		-330000	-280829	-231002	-180511	-129344	-77495	-24952	28294	82253	136934	192348	248505	304805	361249
18	Discounted present worth (EUR)		-330000	-280829	-231002	-180511	-129344	-77495	-24952	28294	82253	136934	192348	248505	304805	361249

2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
14	15	16	17	18	19	20	21	22	23	24	25
5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000
0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1647059	1647059	1647059	1647059	1647059	1647059	1647059	1647059	1647059	1647059	1647059	1647059
5764706	5764706	5764706	5764706	5764706	5764706	5764706	5764706	5764706	5764706	5764706	5764706
-181936	-182391	-182847	-183304	-183762	-184222	-184682	-185144	-185607	-186071	-186536	-187002
-181936	-182391	-182847	-183304	-183762	-184222	-184682	-185144	-185607	-186071	-186536	-187002
0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000	5600000
0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
680882	680882	680882	680882	680882	680882	680882	680882	680882	680882	680882	680882
2383088	2383088	2383088	2383088	2383088	2383088	2383088	2383088	2383088	2383088	2383088	2383088
547500	547500	547500	547500	547500	547500	547500	547500	547500	547500	547500	547500
2930588	2930588	2930588	2930588	2930588	2930588	2930588	2930588	2930588	2930588	2930588	2930588
-75211	-75399	-75588	-75777	-75966	-76156	-76346	-76537	-76729	-76920	-77113	-77305
0	0	0	0	0	0	0	0	0	0	0	0
-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000
0	0	0	0	0	0	0	0	0	0	0	0
-49138	-49261	-49384	-49507	-49631	-49755	-49880	-50004	-50129	-50255	-50380	-50506
0	0	0	0	0	0	0	0	0	0	0	0
-125349	-125660	-125972	-126284	-126597	-126911	-127226	-127542	-127858	-128175	-128493	-128812
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
56587	56731	56875	57020	57165	57311	57456	57602	57749	57896	58043	58191
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
56587	56731	56875	57020	57165	57311	57456	57602	57749	57896	58043	58191
56587	56731	56875	57020	57165	57311	57456	57602	57749	57896	58043	58191
12.9%	13.5%	13.9%	14.2%	14.5%	14.7%	14.9%	15.1%	15.2%	15.3%	15.4%	15.5%
417836	474567	531442	588462	645628	702938	760394	817997	875746	933642	991685	1049875
417836	474567	531442	588462	645628	702938	760394	817997	875746	933642	991685	1049875

Notes	
1	Adjust size until suitable mix between straw boiler and HP
2	Energinet: Technology Data
3	Assume that HP gets it heat from the hot chimney; this results in a very high COP (Technology catalogue).
4	Guess ON-time compared to full load
5	Differential price from utility company (disregarding subscription fees)
6	Price will likely increase
7	Empirical factor from 2016 data
8	Straw consumption is downscaled linearly by the HP fraction
9	Prices depend on season and the contract with the farmers
10	The project account could have an interest rate
11	Interest rate cleaned from inflation
12	Affects the discount rate
13	Discount rate should be greater than or equal to real interest rate
14	The entire investment is assumed financed by a loan
15	kommunekredit.dk, 6 Sep 2017 + 1 percent
16	Undefined the first few years due to the IRR algorithm
17	Simple calculation
18	Uses discount factor which may be different from account interest