Enhancing the self-resilience of high-RES, interconnected islanding areas through innovative energy production, storage and management technologies: grid simulations and energy assessment

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Abstract:

Electrification of heating and transportation can be greatly combined with excess energy production from variable renewable energy sources that exist in many geographical islands. Grid interconnections, where available, play a vital role in the energy system as provide the required balance between energy consumption and demand but many limitations emerge due to cable capacity and other technical constraints, which in many cases, lead to curtailment events. With the minimization of the energy exchange through the cable between islands and the mainland, the islands' self-resilience is enhanced. The islands of Samsø and Orkney are used as the case studies where, among others, the specific technical solutions of a) heat pump districting heating with heat storage, b) electrolyzer for hydrogen production and c) electrical vehicles are examined. The proposed technical solutions are enhanced by Demand Side Management actions utilizing high renewable energy sources availability and curtailment events. The solutions are examined and compared with a reference/current status scenario for each island. This work is based on a detailed model representation, using Modelica language, of the transfer and distribution grid assets, allowing the estimation of the impact of the proposed electrification solutions to the grid level as well as the island level. Simulation results revealed that with the proposed actions in Orkney, annual energy export is reduced by 24 GWh but the corresponding energy imports are slightly increased by 13 GWh, reducing curtailment by 1.4 GWh (77%). As for Samsø, the energy imports are reduced by 5 GWh, while the energy imports increase by 2.0 GWh. Grid losses remain at the same level as before at around 2%, but some distribution lines have significantly lower energy traffic due to higher renewables self-consumption.

Keywords: high RES islands, energy system analysis, grid simulation, energy storage, heat electrification, modelica

1 Introduction

Islands face nowadays important challenges concerning their energy self-sufficiency, self-reliance and decarbonization. Variable Renewable Energy Sources (vRES), currently, contribute a relatively small fraction of energy share on EU level, but thanks to modern advances in storage and control technologies, they stand as a realistic option to cover the energy demand, even by almost 100%. Geographical island areas usually have limited or even no access to the interconnected power grid or most available energy sources, rendering energy supply harder and more expensive than in the mainland. Additionally, part of the produced electricity from variable RES on the islands is quite often curtailed, due to low demand or due to other technical (e.g. interconnection cable capacity, system emergency, maintenance) and non-technical (e.g. low-price periods or other business reasons, bird migration period, etc.,) constraints. However, wider use of recently advanced technologies such as heat pumps and electric vehicles are in position to absorb any excess of electrical energy production and transform or store it into various energy vectors covering the versatile energy needs of the islanding population.

Islanding areas have important limitations in energy production due to their physical boundaries and thus, energy demand has to be adapted or transformed based on the available resources and imports to cover the requirement of each vector [1]. Variable RES technologies such as Wind Turbines and PVs have been identified from their very beginning [2] as possible solutions in sustainable energy provision, as wind and solar resources are usually in abundance and as their energy parity has been achieved earlier than in the mainland due to the high cost of the fuel that is substituted [3]. The technical limitations, especially on non-interconnected islands originated in fluctuations in production due to sudden energy losses or even predicted power reductions due to diurnal resources variation, causing grid stability problems and mismatch between supply and demand [4]. Due to this fact, there is a constant necessity for rotating power reserves to cope up with and as a result, the maximum penetration of renewable energy sources is limited to a percentage of around 30%. This penetration limit is even lower in smaller islands as the distribution of RES is affected by the same micro-area meteorological/resource [5]. To increase the RES penetration, using more than one RES technologies, especially PV and wind is a proven, well-established viable solution [6] as one can fill the energy production gaps of the other. In interconnected islands, similar limitations exist as the interconnection cable has important power transfer limits.

Other RES solutions, suitable for islands that have been proposed towards self-sustainable islands, are hydropower and biomass [3] or combinations of internment and non-internment RES [7]. Furthermore, RES technologies suitable for islands are the marine (or oceanic) technologies, namely, wave and tidal energy systems for electricity production, solar thermal systems for power production in CSP systems, or in local or centralized heating systems, and geothermal production given that geothermal potential is available in the island [8]. Enabling a wide portfolio of RES for covering the demand of electrical and heating needs, the overall energy system becomes more resilient, versatile, and consequently, more efficient and less prone to outages or supply problems [9], [10].

Storage technologies, coupled with RES provide an effective way to match supply with demand in both the electricity and heat vectors [11] and thus, provide flexibility on both sides of supply and demand and for almost all energy vectors. The further advancement and marketization of storage technologies in private households or centralized systems are at the heart of scientific research. For electrical storage, batteries (BESS) can provide energy and power support to local autonomous grids or weak grids inside islanding areas, to maximize RES contribution, whilst they can provide ancillary services such as voltage and frequency regulation and reactive power support [12], for the DSOs/TSOs. Additionally, where applicable, pumped hydro storage systems are currently more and more frequently installed in islands, since their storage capabilities are currently the highest available, flattening the demand curve and absorbing any excess of energy producing, whilst reducing curtailment, and supporting demand response actions [13].

Centralized thermal storage for heating offers a solution that can be applied to many islands, combined with district heating (DH), from the very small, for example, in the case of Agios

Efstratios in Greece or larger ones such as Samsø in Denmark [14], [15]. These systems are currently using oil or biomass boilers for heat supply, but since excess electrical energy exists, other technologies can be used to provide the necessary heat while the biomass can be used in transformation processes such as liquid biofuels for transportation. Currently, one of the most efficient Power-to-Heat (P2H) concepts is based on the use of heat pumps (HPs), for at least short-term storage [1], [16], [17].

Transforming excess electricity to hydrogen is a promising energy storage option and currently being promoted by industry and research. Large-scale electrolyzers are being installed in islanded areas [18] [19], producing hydrogen that can be used in a wide spectrum of applications, such as sea transportation in cooperation with fuel cells, without excluding electricity, or heating needs with the introduction of High temperature (HT) – Proton Exchange Membrane Fuel Cells (PEM FC) technologies. Hydrogen production and storage is a promising option when a surplus of RES exists or when it is about to be curtailed [20].

The electrification of applications and services that previously had been dependent on fossil fuels such as heating and transportation is a technological challenge that can lead to energy sustainable communities. This challenge is bigger in islands due to the above-mentioned grid-related limitations. On the other hand, excess electrical energy is an already paid resource that is not a good practice to dump or curtail. In this respect, the EU funded SMILE project (www.h2020smile.eu) has examined various solutions to increase the level of electrification in islanding regions. Indicatively, boat charging with Demand Response algorithms have been applied on Samsø. On the Orkney islands, heat storage solutions (phase change materials and water) coupled with heat pumps have been successfully demonstrated. In all sites, advanced controls have been installed to facilitate the demand response actions.

The main objective of this study is to assess the impact of island-scale electrification solutions and technologies, aiming at reducing curtailment events, enhancing the islands' grid self-resilience, self-reliance and decarbonization process on the residential, transportation, agricultural, industrial, land use, and waste sectors in electrical energy and heat vectors. Additionally, this study will assess the impact on the grid by these solutions. The interconnected islands of Orkney and Samsø have been selected, implementing various energy management and storage strategies. These strategies take into account the status of the interconnection, meaning if energy is imported or exported from the island to the mainland or when curtail events occur, in order to maximize RES usage and reduce imports from the mainland, and thus achieving a higher level of energy autonomy. The solutions that will be examined include in brief: a) the introduction of heat pumps in a1) district heating networks, or a2) in local premises, b) the introduction of a medium-scale electrolyzer for hydrogen production and c) an extensive use of electric vehicles. The generalized system is presented conceptually in Figure 1.

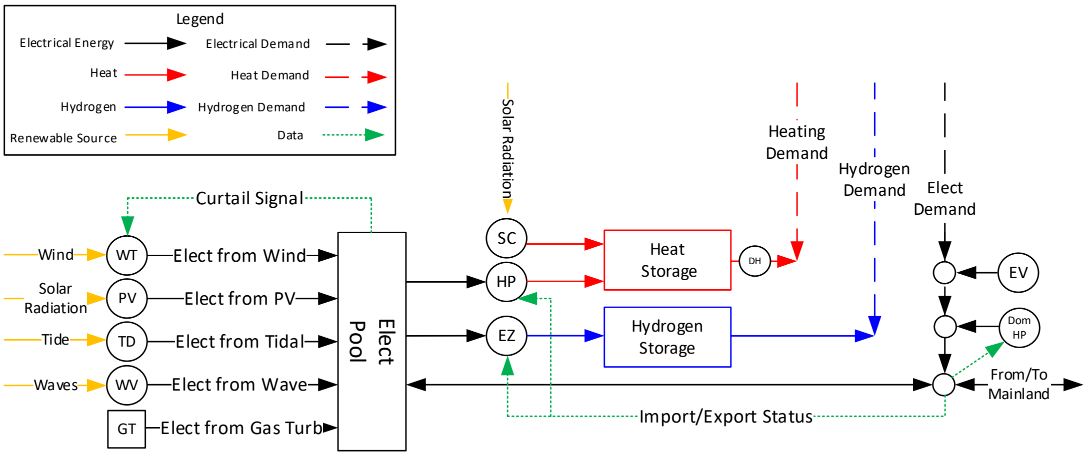
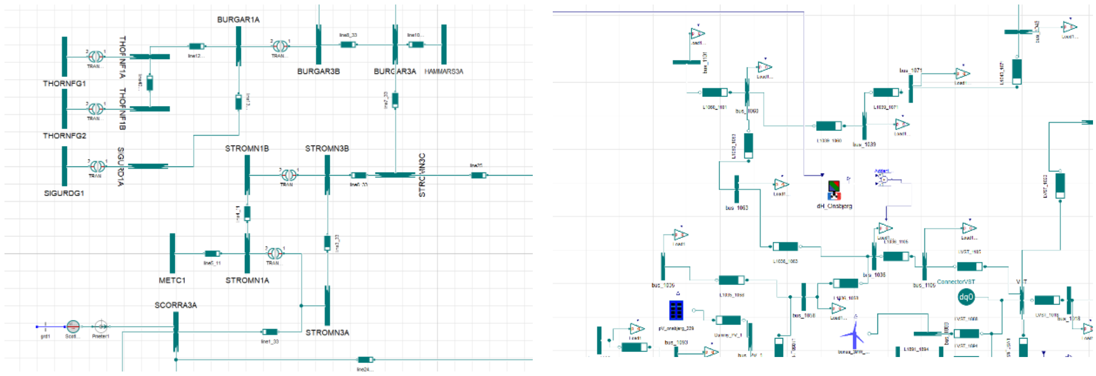


Figure 1: Generalized System with energy and data flows.

District heating and power system modeling and simulation as a combined system (e.g. Hybrid distribution systems) has not been studied extensively in the past. A very interesting recent study has been published in [21] providing a methodology for optimal solutions in terms of configuration and control in the hybrid simulation of power system and district heating, with interconnected PV, setting as main target the minimization of electrical energy import from the grid. Nevertheless, the proposed optimization procedure has a complex implementation, using co-simulation techniques across three different commercial software tools. As stated in [21], existing approaches are not suited for detailed technical assessments that are required for network and consequently ,there is a need for new tools and methods. Many studies, cope with hourly simulation based on rough assumptions, logistic models, and energy balances [1] [22], [23]. In this work, the electric grid of the under-investigation islands is modeled meticulously (Figure 2) using dedicated libraries and the impact of all the proposed technologies on the electrical grid behavior is assessed for various configurations and operational scenarios on island level as demand side management is enabled in the controllers/energy management components with rule-based control. Moreover, the simulations are minute based, taking into account fluctuations and events such as power curtailment with small duration but with great impact on the performance of the whole energy system, leading to more accurate conclusions than performing the energy flow analysis on an hourly basis or higher.

The grid representation for the two case studies islands, includes all the basic grid assets, such as lines and transformers that connect two voltage levels for each island namely 60kV/15kV for Samsø and 33kV/11kV for Orkney and the advanced assets that are considered and modelled in this study are grouped into four categories: a) energy production technologies; b) energy consumption technologies; c) storage technologies; and d) energy management systems.



Orkney 33 kV Grid (Detail) Samsø 15 kV Grid (Detail)

Figure 2: Modelling the Electrical Grid of the two islands in Modelica, using PowerSystems Library

2 Methodological Concept

To estimate the behavior of high-RES interconnected systems, for a number of interventions, a detailed software representation of the whole grid topology on the level of HV/MV has been developed, representing the reference (current status of operation) scenario, followed by models which represent the future operational scenarios. All models are created using the detailed grid modeling tool that is described in the next paragraph. The reference scenario includes the current production units and electrical demand data from historical repositories that have been allocated to the grid loads in each MV/LV transformer. Each future scenario is based on the reference scenario grid, with properly connected new components e.g. power loads and production units. This comparison between reference and future scenarios of operation, contributes to the assessment of the implementation of the proposed technologies in each islanding area.

The scenarios developed in this work can be sorted into two groups. Those oriented to the district level, focusing on a specific area, or asset of an island (e.g. the district heating or heat pump installation in an area) and islands level.

The study has been accomplished by using detailed grid models developed in Modelica language using PowerSystems library [24] simulated using Dymola tool. PowerSystems is capable of performing dynamic or quasi steady-state simulations [25] and has been developed in the context of the research project MODRIO/ITEA2 whose purpose was to extend modelling and simulation tools all phases of the development cycle — from early concept design, detailed system design, to verification and validation [26], [27]. PowerSystems library has been used in similar studies [28] and a brief introduction to the library can be found in [29]. In this study, quasi steady-state simulations have been carried out as both islands are interconnected with the mainland. Dynamic/Transient simulations for the islands systems have limited added value to the level of examining any fault operation, since the system dynamic response depends on the mainland conventional production/inertia. The results may quantify key operational parameters for a typical power flow analysis, such as the bus voltage, voltage angle, power transferred in each line, grid losses, voltage drop, etc. The quasi steady-state simulation is based on hourly demand and production values, but the selected solvers (Dassl, Dopri45 and Randau IIa) use variable step size; thus, increasing the accuracy, since the various energy management events (e.g. SoC thresholds, export levels) occur frequently.

The modeling tool has the capability of using blocks and connectors to represent the grid. Consequently, each grid asset is represented by a model block. A block may consist of many other blocks, providing this way cascade modeling, which ensures flexibility in modeling and easy-to replicate components/models in various instances.

Modelica makes possible and easy to implement customized energy management solutions, examining this way a large number of alternatives. Other tools, such as EnergyPlan, Homer, or RETScreen, are representative of one node models [30] and cannot be used for complex systems, similar studies and/or cannot provide similar results with this level of detail as they have many limitations in network representation, Energy Management Systems (EMS) control customization, and solver capabilities [23], [31]. Similar works in Samsø and Orkney have been performed using EnergyPlan [1], [32], but due to certain capabilities of this software, they refer to a conceptual-design level of detail. The present work intends to provide a higher level of detail, while being in position to calculate key power related variables (not only electricity, but also heating/cooling ones).

This work, with the above-mentioned type of modeling, effectively combines the heat and the electric domain. All decisions made on the EMS of the district heating systems (e.g. heat pump operation), or in the electrolyzer system, will have an imminent and traceable impact on the local grid and the power flow-related parameters. To evaluate the impact of the proposed solutions, a reference scenario is developed and modelled for each island representing the current status, followed by a number of alternative scenarios representative of their near-future energy transition. For Samsø and Orkney, future scenarios plans have been developed with a horizon to the year 2030. This work aspires to move forward the proposed energy transition plans presented and evaluated in [1], by using detailed modeling and assessing the impact of the proposed interventions on the grid. The future scenarios cases studies presented in this work are heavily based on the future scenarios related to the SMILE project, past study of Marczinkowski and Østergaard [1] and personal communication with local stakeholders and energy planners.

2.1 Samsø Case Study

2.1.1 Reference Scenario

Samsø island is interconnected with the mainland through underwater cables with rated voltage of 60 kV. There are two inter-connection points. One in the city of Odder (West, Substation KNU-KNUDSMINDE), and one in the city of Begtrup (North, Substation BEG-BEGTRUP) (Figure 4) forming a network ring. However, the northern cable is idle, since it is used only for backup. The island has most of the time excess electrical power and therefore exports renewable electricity to the mainland (Jutland), via these two connections. The rated nominal capacity of each cable is about 40 and 22 MW_e in the West and North, respectively.

Samsø has only renewable electrical power production systems. The wind systems consist of 11 Bonus wind turbines onshore (11× 1 MW_e) at 50 m hub height at various spots, 10 Bonus wind turbines offshore (10 × 2.3 MW_e) at 61.2 m hub height placed at the sea area at the south of the island and a few others smaller with total installed power 359 kW_e. The photovoltaic systems have installed power in total, about 1373 kW_p, in 193 separate systems (data till March 2017).

Samsø domestic heat demand is partially covered by four district heating networks, each one mainly powered by biomass boiler. The list of all the district heating thermal plants is presented in Table 1. The heating demand has been estimated for the whole island based on the heating degree hour method and has been transformed/scaled accordingly in order to correspond to the expected load of each district heating plant. This is an assumption as there are no specific data for each DH plant.

Table 1: District heating systems in Samsø

Name	Technology	Capacity (MW_{th})	Proposed Heat Pump & TE Storage
Ballen-	Straw	1.6	0.3 MW_e / 1.56 MWh
Brundby	Oil	2.0	
Nordby-	Woodchip	0.9	0.55 MW_e / 3.16 MWh
Maarup	Solar/ Oil	2.2/1.4	
Tranebjerg	Straw	3	1 MW_e / 2.6 MWh
Onsbjerg	Straw	0.8	0.15 MW_e / 0.78 MWh

2.1.2 Future Scenario

The general idea for Samsø for its near-future scenarios of operation is characterized by the total electrification of the residential district heating sector by replacing the in-operation district heating biomass boilers with heat pumps and the savings in biomass fuel to be used for the production of biogas for transportation uses. These electrification actions are a step towards Samsø strategy for reaching carbon neutrality. The proposed capacity of the heat pumps and tank storage for each DH are given in Table 1. The installed heat storage is estimated to cover approximately an average load for 3 hours. Additionally, the extensive use of electric vehicles is considered, and 2000 of them are assumed to be in circulation by 2030, adding 6 GWh in annual electricity consumption with a mean value of 8.2 kWh per car and per day. The installation of an electrolyzer is examined with a capacity of 1.5 MW, creating an extra electrical consumption of 2.1 GWh per year. This value corresponds to about 1400 hr of operation at full power per year. The annual production of hydrogen will be around 4.2 10^5 Nm^3, with an average specific consumption of 5 kWh/Nm^3.

Additionally, the case of domestic use of heat pumps in individual houses, instead of oil boilers, is examined for 275 individual houses[1] covering heating needs of approximately 10.44 GWh. The same heat demand profile as for the district heating will be used, scaled accordingly, and by using an average COP=3, the electric power of these heat pumps will be around 821 kW_e. From the production side, the PV electricity generation is expected to increase by adding 10 MW_p by 2030.

The above demand and production components have been distributed in various scenarios, which are summarized in Table 2. The 2016 Scenario (Reference) serves as the baseline. There are four 2030 Scenarios (Future A, B, C and E) each one corresponds to one different Heat Pump Energy Management System (HP EMS) (1 to 4) that govern the operation of the heat

[1] number derived after personal communication with Samso stakeholder

pump and storage in all the DH and one 2030 Scenario (Future D), which includes the domestic heat pumps, along with the HP EMS 3 for DH. The various DH EMS strategies are presented in detail in chapter 3.

Additionally, for scenario Future C, a sensitivity analysis with larger heat storage for all the district heating units (1.5, 3, and 6 times larger than the proposed sizes) will be carried out. A visualised overview of the scenarios is presented in Figure 3 .

Table 2: Samsø Simulation Scenarios

	Reference	Future A	Future B	Future C	Future D	Future E
Number of EVs	-			2000		
DH Heat Pump (MW_e)	-			2.0		
Storage (MWh)	-			8.1		
EMS	-	HP EMS 1	HP EMS 2	HP EMS 3	HP EMS 3	HP EMS 4
Electrolyzer (MW)	-			1.5		
Wind (MW)			34.4			
PV (MWp)	1.373	11.373	11.373	11.373	11.373	11.373
Domestic HP (MW_e)	-	-	-	-	0.821	-

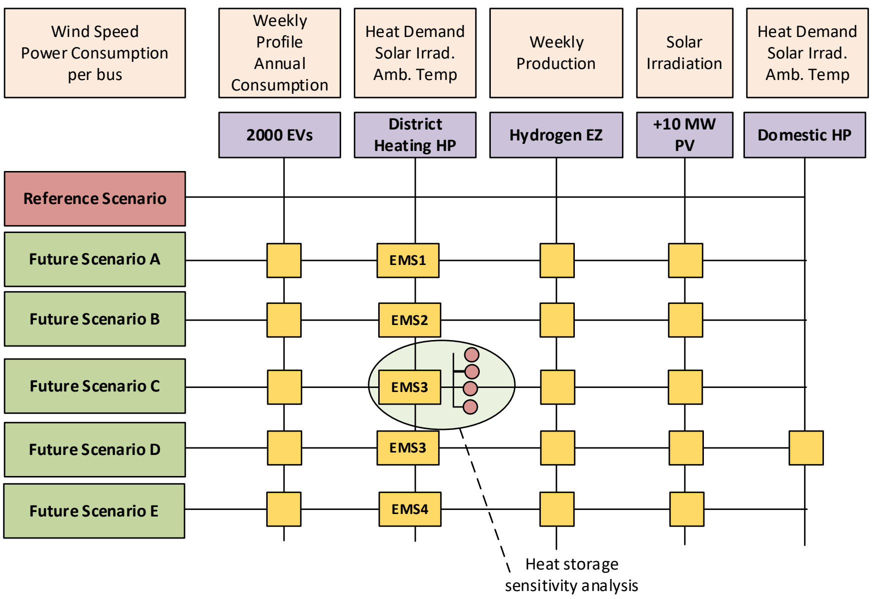


Figure 3: Mapping of the scenarios for Samsø

2.2 Orkney Case Study

2.2.1 Reference Scenario

Orkney is an archipelago of around 16 inhabited islands and its electrical system is part of the Scottish & Southern Hydro Electricity Network. The interconnection voltage among the

Orkney islands is 33 kV, which is also the same as the interconnector to the Scottish mainland. Two cables connect mainland Scotland to Orkney with a combined capacity of 40 MW_e. The connection point is in the town of Thurso with two cables as it is depicted in Scottish Hydro Electric Power Distribution long-term development statement schematic diagram for Scorradale [33]. The first cable had been installed in 1982 and the second in 1998 [34]. The Orkney grid is divided into electrical zones; each one includes islands or a part of an island. Figure 5 shows a significantly simplified version of the 33 kV grid of Orkney, with a focus on the islands of Zone 1a. Where the 11 kV connections are depicted, the connections to the smallest islands in this zone are also included. The 33 kV grid forms a loop around most of the inhabited islands. Figure 5 guides the development of the electrical model in Modelica. The 33 kV model is the top-level model and the islands of Rousay (with connections), Westray (with connection) and Eday, are separate model blocks.

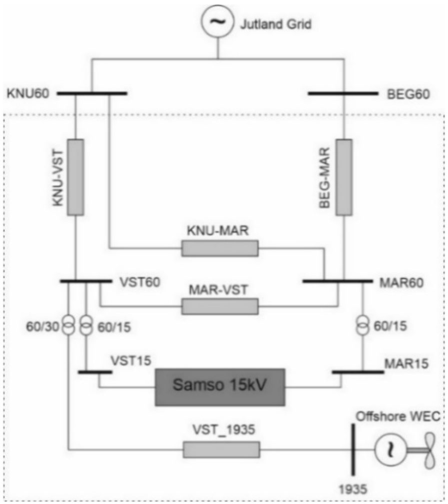


Figure 4: Samsø 60kV Network

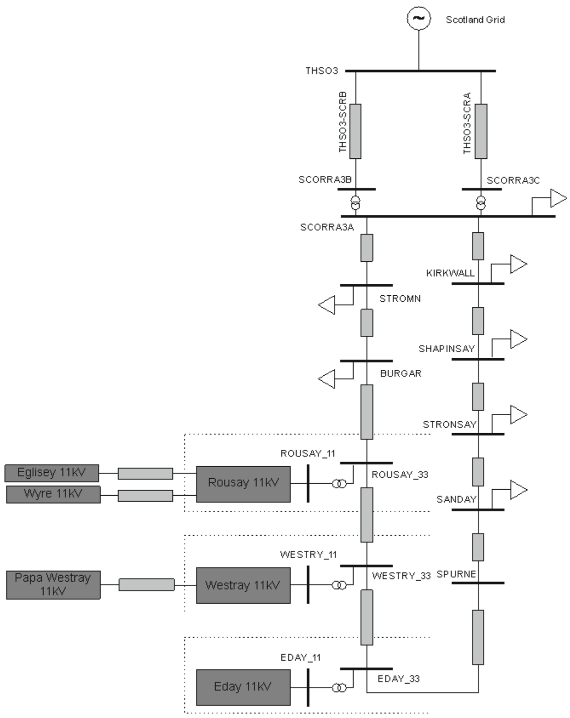


Figure 5: Orkney 33kV electrical Grid, with the detailed parts of the islands of Zone 1a

Orkney power production system consists of a mix of conventional and renewable energy sources. There is only one conventional gas turbine (10.5 MW_e) [35], as part of CHP unit in the Flotta Oil Terminal, primarily for the needs of the terminal and secondarily for providing power to the local grid [36], and a backup generator in Kirkwall that is not used under normal circumstances. In Orkney, a large number of wind turbines (single turbines or in small parks) have been installed in most of the islands. After extensive research in various online sources and reports [37]–[47], all major in-operation wind turbines have been identified in terms of model, height, and location and included in this study. These turbines are connected to the 33 kV or 11 kV grid. The most common model of the installed wind turbines is the 900 kW Enercon E44, which is used in all community-owned turbines. The total installed capacity of the wind energy plants is estimated at 48,500 kW. Moreover, there are around 1300 kW_p of installed photovoltaic systems distributed in the island complex. Orkney is well-known for hosting test sites for ocean energy systems [48] that are interconnected with the local 11 kV grid, providing energy to the national energy system. The total power ratings of the transformers for the tidal test site, installed on the island of Eday (Fall of Warness), are 4 MW_e. Moreover, there is a 7 MW_e transformer power rating for the wave test site, installed on the mainland island (Billia Croo). In this analysis, a 2 MW_e tidal energy system has been considered, based on the tidal turbine SR2000 and 3 MW_e wave energy system using 4 Pelamis engines, 750 kW_e each. Due to interconnection cable power transfer restrictions, energy production from wind systems has to be curtailed by taking offline wind turbine systems. Curtailment reduces production from community-owned turbines as they are located in zones where curtailment events are forced. In some turbines, the curtailment is around 30% on a yearly basis [49]. For the purposes of this work, it is assumed that the only restriction for having a curtail event is when electrical power export to the mainland reaches 30 MW_e.

2.2.2 Future Scenario

For the Orkney Future scenario, a portfolio of interventions is proposed to increase electricity usage against other energy vectors and to reduce energy curtail from wind systems. These interventions include a district heating network that will be built from scratch to cover the heating needs of 1/3 of the Kirkwall population and will be using electrical heat pumps as primary heating technology, which corresponds to 29 GWh of heat production. To cover this demand, and with a modest COP equals to 2.5, the total heat pump electrical power is estimated at 3.43 MW_e with heat storage of 17.85 MWh. By 2030, two electrolyzers with capacities of 500 kW in Eday and 1 MW in Shapinsay will have been installed , under the framework of various projects such as Surf n Turf and BigHit [50], [51]. These electrolyzers will increase electrical energy demand by 4.2 GWh, which is translated into 2800 hr of annual operation producing around 8.4 10^5 Nm^3 of hydrogen. It is foreseen that 10,500 electric vehicles will be in circulation at that time. These EVs are going to add around 27 GWh to the electrical energy demand of Orkney which is translated to an average 7.05 kWh per car and per day. To support and flatten the local production curve, 10 MW_p of PV and 10 MW_e of tidal energy production systems are going to be installed on the island by 2030.
To address the future interventions, five scenarios have been formulated and investigated. The 2018 Scenario (Present) serves as baseline aiming to identify the current status. One 2030 Scenario (Future A) that consists of the new energy production units but without the energy consumption solutions. Future B scenario (2030) includes the Electrolysers, District Heating network and electric vehicles without new power production units. Future C scenario (2030) includes the demand and all production interventions. The fifth, Future D scenario includes the Eday Heat Electrification case based on the curtail events of the Future C scenario.

Regarding the last Future D scenario, as has been mentioned in the introduction, the individual HP installation in local premises (Power2Heat – P2H) is examined in the context of SMILE project. For that reason, the P2H solution is examined in all the houses of the Eday Island. An analysis has been conducted in [52] about the number of houses, the occupancy, their size, and their consumption in the area. This analysis led to the identification of 5 house types, which are representative of the total of 85 houses in the island. To estimate each house heating load, a top-bottom approach was selected.

The heating needs for Orkney have been estimated to be 123.54 GWh, and the total dwellings are 11,228 [53] but their occupancy is 9.8% [54]. Take into account this data, the heat demand is 12.20 MWh per dwelling and is in agreement with online sources for heating needs in the UK [55]. According to statistical data for Orkney, 1.37% of Orkney dwellings have only one room, 14.38% have two rooms, 30.02% have three rooms, 36.19% have four rooms, 15.84% have five rooms and 12.20% have more than six rooms and total number of rooms are 44,223.

With 90.2% occupancy, the average annual energy needed for heating an inhabited room is 3.1 MWh.

Assuming that the 85 Eday houses follow the distribution of houses for Orkney, for modelling purposes, there are the following houses in Eday: 1 house with 1 room, 11 houses with 2 rooms, 22 houses 22 with 3 rooms, 27 houses with 4 rooms, 14 houses with 5 rooms and 10 houses with ≥ 6 rooms.

In respect to the above listed 90.2% occupancy, the per room heating demand and for modelling purposes, the number of houses being used for electrification for the Eday island is presented in Table 3 along with their annual heat demand, the proposed heat pump size and heat storage size, as have been proposed in the context of SMILE project. These are considered to be a Daikin HP and Sunamp PCM heat storage [56]. In this case, the heat pump thermal power is not steady but is adapting dynamically according to the heat load. All houses considered to have the same energy profile but scaled accordingly to meet the above-mentioned annual values. The total sizes of the components for Orkney for each scenario, are summarized in Table 4. A visualised overview of the scenarios is presented in Figure 6

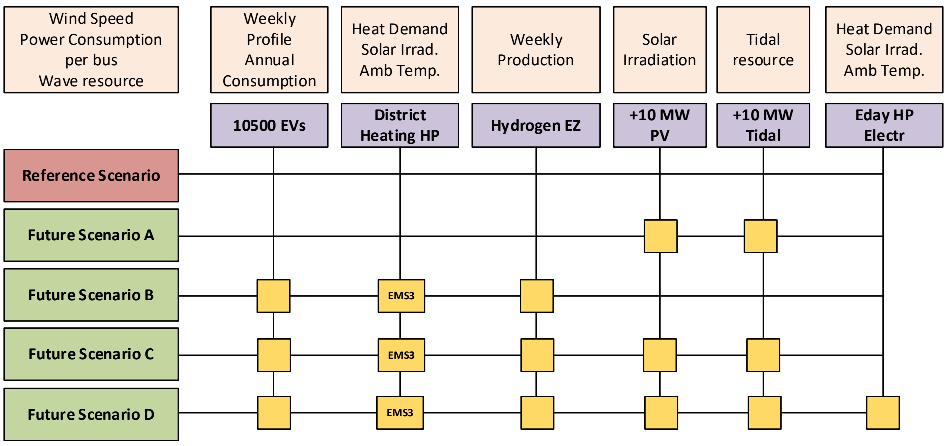


Figure 6: Mapping of the scenarios for Orkney

Table 3: The installed capacities of the heat pump and heat storage for each house.

House Type	Number of Houses	Annual heat demand (MWh)	Heat Pump Size (kW)	Heat Storage (kWh)
Two Room	11	6.2	11	3
Three Room	20	9.3	11	6
Four Room	24	12.4	11	9
Five Room	12	15.5	16	18
Six Room	10	18.6	16	18

Table 4: Orkney Simulation Scenarios.

		Reference	Future A	Future B	Future C	Future D
Number of EVs		500	500	10,500	10,500	10,500
DH	HP (MW)	-	-		3.43	
	ST (MWh)				17.85	
	EMS				HP EMS 3	
EZ (MW)		-	-		1.5	
Wind Systems (MW)				48.5		

PV (MWp)	1.3	11.3	1.3	1.3	11.3
Tidal (MW)	2.0	12.0	2.0	12.0	12.0
Wave (MW)			3.0		

3 Model Development

Each island grid has been developed using the parameters of the actual lines (resistance and reactance, lengths), and transformer data received by islands' authorities in GIS [57], [58] According to the data, specific distribution substations/transformers have been identified. Based on the electricity demand time series received by the SMILE partners [59] for the reference year, the active power demand time series for each bus has been estimated.

The next sections present the models of energy consumption components and energy production components that have been used in the scenario simulations. In general, all energy production systems (Wind, Photovoltaic, Tidal, Wave, and Gas Turbine) have been modeled as active and reactive power (PQ) sources and the electrical energy demand systems (District heating, Electrolyzer and EVs) have been modeled as active and reactive loads.

3.1 District Heating Power Plant

For the district heating power plant, two base models have been developed. The first model contains a solar thermal heat source, the heat pump, and a heat storage tank (Figure 7) and the second model is similar to the first one but lacks the solar thermal heat source. The input and output variables and the design parameters are presented in Table 5.

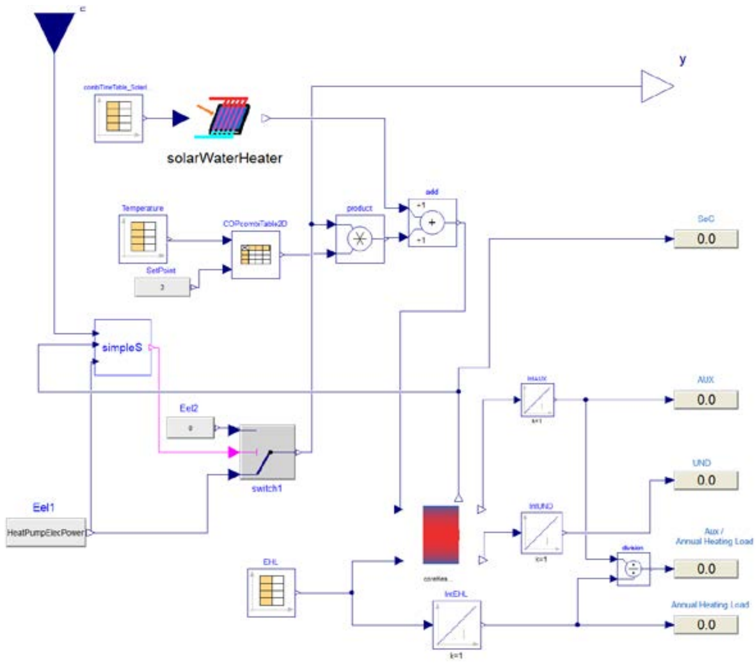


Figure 7: District Heating Model

Table 5: District heating variables and parameters

Input Variables	Design Parameters	Output Variables
Heat Demand Time Series	Electrical Power	Electrical Demand Time Series

Elect. Energy send to mainland signal	Heat Tank Size	Thermal Peak Power Time Series
Solar Irradiation Time Series	COP vs Temperature	Heat Losses
Ambient Temperature Time Series	Solar System Size and efficiency	

The solar thermal heater source model is a simple (passive) component that transforms the solar irradiation into heat with an average efficiency value (η_{sc}=40%). The heat pump model has been implemented in two phases. In the first phase, a detailed dynamic model has been developed considering all operational details. This model has been simulated for various ambient temperatures and thermal loads in order to estimate the COP in all possible conditions. This model has been presented in [60]. The estimated COP for all the cases has been tabularized and integrated into the district heating model (second phase) as a lookup table, at which the inputs parameters are the ambient temperature and the thermal load. It is assumed that the heat pump thermal power is steady and cannot be regulated.

3.1.1 Heat Pump Energy Management Systems

Heat pump operation, in general, is driven by the energy cost and other business-related parameters. The electricity price is dictated by the Nordpool market and as a general rule, the price is lower during the night, and there are two peak prices during the day; morning and afternoon. However, as one of the objectives of this study is to minimize cable usage, the HP operation in the examined scenarios will be based on the surplus of local energy production. Therefore, the Energy Management System (EMS) operation strategies that are developed and investigated are based only on the technical point of view and no cost-related aspect is taken into consideration.

The HP EMS takes as inputs: i) the heat storage State of Charge (SoC), ii) the power flow signal, which provides the amount of power that currently is exchanged from (or to) the island to (or from) the mainland and iii) the current operational status (ON-OFF) of the heat pump. The decision of the HP EMS is to turn ON or OFF the heat pump based on the inputs. Taking into account these inputs, energy management scenarios (set of rules) can be identified and implemented.

The first set of rules formulates the 1st energy management scenario (HP EMS 1) and is the simplest heat pump operation, during which the heat pump operates when the heat tank is not full and stops operating when the heat tank is full, regardless the status of the island electricity import/export (without demand response).

The second set of rules formulates the 2nd energy management system scenario (HP EMS 2), which refers to an advanced system (with demand response), during which the heat pump stops operating when storage is full or when there is no sufficient electrical energy to export. In addition, the heat pump starts working if the heat tank is totally empty (SoC=0) regardless of the import/export status, but when there is an export of power then the heat pump starts operating, charging the heat tank.

The third set of rules formulates the 3rd energy management system scenario (HP EMS 3). In this scenario, the heat pump operates in a narrow band of SoCs. Specifically, when the island exports electricity to the mainland, the SoC of the heat battery is designed to maintain in-between 1.00 and 0.85. When the island starts importing electric energy, the heat pump stops operating and the SoC starts decreasing, owed to heat demand. If the SoC goes down to 0 (meaning that there is no excess electricity), then the heat pump operates to charge the heat storage SoC from 0 up to 0.15, to cover the current needs and not to store. When sufficient electric energy is available, then, the heat storage is fully charged from the heat pump.

These previous three HP EMSs can assure that there always is enough heat to cover the demand (taking as a fact that heat pump power will be able to cover the peak heat demand). In the 4th energy management scenario (HP EMS 4), when no electricity is exported, the heat pump does not operate, and thus heat demand is not covered when the heat storage is empty. The heat demand has to be covered by another heat source, such as the biomass boilers (already installed in the DH systems). When excess electricity exists, the heat pump works around the SOC band of 0.99-0.85 as in EMS 3.

The heat storage model takes as input the district heating demand and the heating production from the heat pump and solar thermal system (if available) and calculates the SOC_{HS} (based on energy balance). The energy that cannot be stored is lost (has to be zero), and the peak energy/power, when necessary to cover the demand, is provided by a conventional boiler. The heat storage model does not take into consideration the heating dynamics and water temperature (enthalpy) input/output values as modeling the district heating heat domain is out of scope of the current study, and there are not enough data to proceed (such as input/output network temperatures).

3.2 Electrolyzer

The electrolyzer model considers as an input variable, the power flow signal, which provides the amount of power that is currently being exchanged from (or to) the island to (or from) the mainland. If power is exported (Samsø) or curtailed (Orkney), the electrolyzer operates. Additionally, it takes as design parameters the weekly hydrogen production (or weekly hours of operation, or weekly energy demand for hydrogen production) and the active power of the electrolyzer. The output is a time series of its operation status and consequently the electrolyzer power consumption profile.

The electrolyzer has been modeled as a constant load and includes the electrolyzer EMS that controls its operation with ON-OFF signals. Electrolyzer must operate for a specific amount of time per week to produce the required quantity of hydrogen. It operates only when the island exports electrical energy (in Samsø) or when an energy curtail event occurs (in Orkney) and its weekly operation time (or hydrogen production) is less than the required goal. The electrolyzer stops operating when the island imports energy (for Samsø) or when energy production is not to be curtailed (for Orkney); or when the weekly operation goal has been reached. If the goal has not been reached, the EMS will start electrolyzer operation even if there is no excess energy, at an appropriate time (that it is estimated accordingly with the amount of hydrogen that has been produced till then) before the week ends in order to reach the weekly hydrogen production goal. The model is presented in Figure 8.

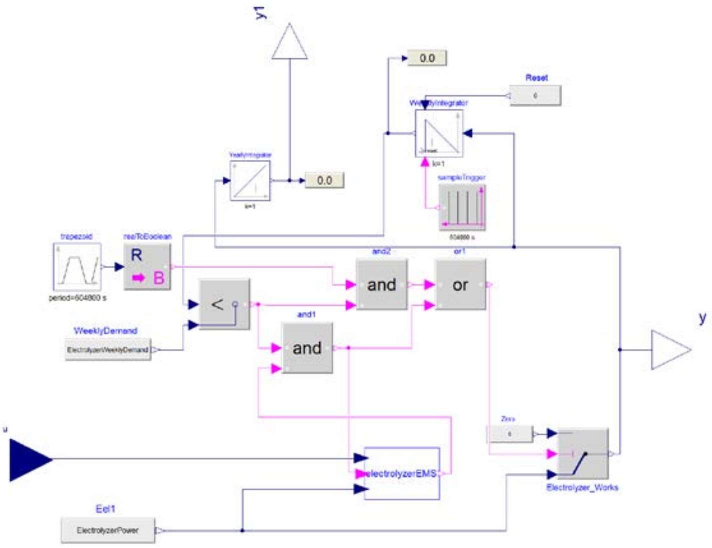


Figure 8: Electrolyzer model, with the relevant EMS block

3.3 Electric Vehicle consumption estimation

To estimate the distribution of the EVs additional power load, literature models are used, since it is out of scope of the current study, to model the behavior and characteristics of each car and drivers' behavior, as this is a multifactor problem to address. The main parameters that guide the charging behavior are i) the cost of electric energy and its variation throughout the day/week, ii) the availability of charging points, iii) the current battery SoC and iv) the duration of charging. Adapting the results from [61] to the specific EVs fleet, a new demand time series is created, based on a weekly cycle. Although this is a rough assumption, there is no better alternative owed to the fact that the use of EV's is still on a limited scale and the demand response techniques are out of the scope of this study. The EVs weekly demand profile is presented in Figure 9.

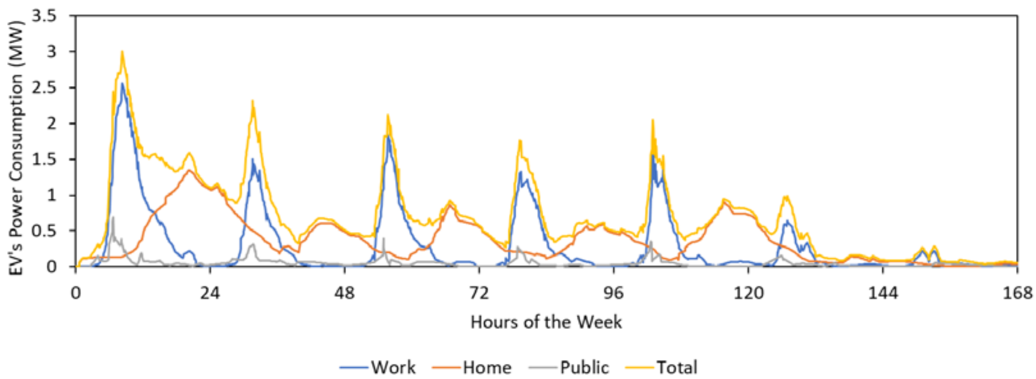


Figure 9: EVs power consumption weekly profile

3.4 House heating with integrated storage

The house heating model block with storage is presented in Figure 10. The model inputs / time series variables are:

- Ambient Temperature for the estimation of the COP of the heat pump
- Heat demand for each house
- Availability of curtailed power

There is only one output variable, which is the power demand for heating of the house, which is added to the grid load in the local bus.

The heat pump has been modeled and simulated separately and the COP curves have been extracted for various temperature differences and heating loads. These COP curves have been introduced to the house model (instead of the actual dynamic heat pump model), in order to reduce the simulation time. The main blocks that comprise the house are: a) the heat pump, b) the heat exchanger for transferring heat from the heat pump to the PCM heat storage and c) the heat storage with the charge controller. The houses are distributed randomly in various locations/buses in the island as in the detail of Figure 11. For simulation purposes, each house type has a single instance in the model. During normal operation, the HP works only to cover the current energy needs, when in curtail, the HP works at a higher power to charge the heat battery, while covering the heating needs.

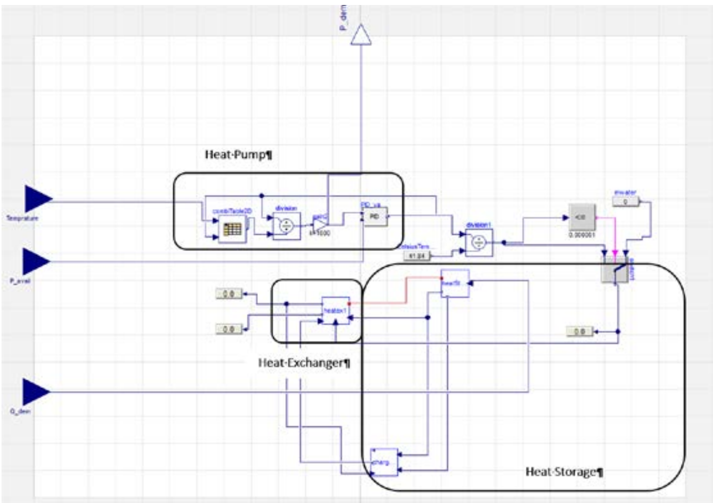


Figure 10: The house heating model block with storage

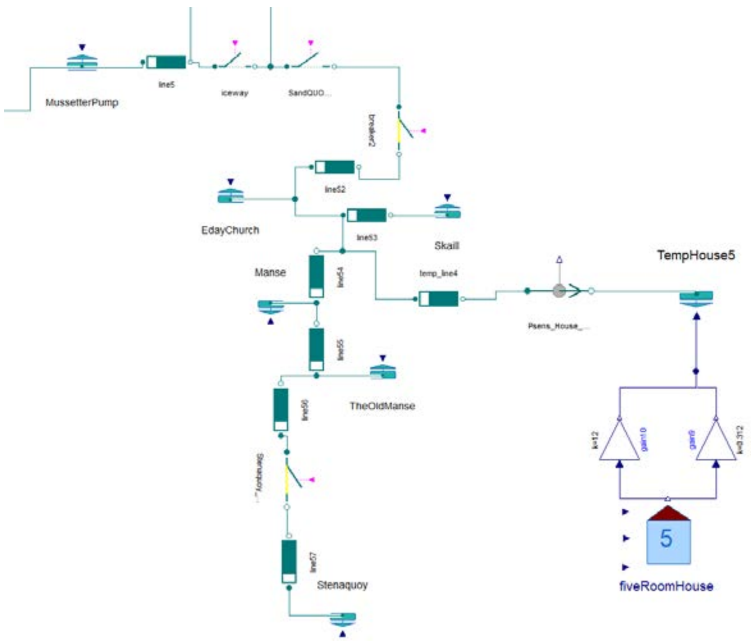


Figure 11: Detail of the Eday Modelica model with a house installed in random location

3.5 Energy Production Units Models

3.5.1 PV

The energy production from PV systems is modeled with the assistance of Renewable Ninja website [62]–[64]. For each demo site, power production from PVs is acquired on hourly granularity from the website based on the installed power of each scenario and connected to the grid at the appropriate connection points/buses. As mentioned, the PV systems are treated as PQ sources. The reactive power coefficient is assumed steady and equal to 0.95. Typical crystal PV panels on the optimal plane are considered.

3.5.2 Wind

The energy production from Wind systems is modeled with the assistance of Renewable Ninja website [62]–[64]. For each demo site and wind turbine the power, the production is acquired on hourly granularity from the website based on the specific turbine model and specific hub height that is identified from various sources. Same as PV systems, the wind systems are treated as PQ sources. The reactive power coefficient is assumed steady and equal to 0.95.

3.5.3 Tidal

The selected tidal turbine is the model SR2000 as it is installed on the island of Orkney (in EMEC tidal test facility) during the study period. As most of its technical and performance characteristics are confidential and hard to get, a representative power curve is acquired, digitized, and used for the power production estimation based on the literature [65], [66]. In general, the estimation of the power provided by a tidal turbine follows a similar procedure with the estimation of the power produced by a horizontal axis wind turbine, with the main difference being the working medium (water instead of air). EMEC provided the resource time series for a year (2005) and has been used as input to the model.

3.5.4 Wave

The wave turbine that has been selected is the Pelamis wave turbine as it was installed on the island of Orkney during the reference year. Analytic wave turbine modelling is far too complex and out of the scope of this study. Following a comprehensive literature survey, the power matrix of the Pelamis engine has been found and used [67]. The produced power of a Pelamis Engine is a function of the two most important wave energy statistical characteristics, the Significant Height and the Energy Period. The wave turbine has been modelled with the help of the power matrix, and with linear interpolation, provides the power production for each set of H_s and T_e. Both of these statistical time series values have been provided by EMEC for a year (2005) and have been used as inputs for the model.

4 Results and Discussion

4.1 Samsø Results

4.1.1 Energy system analysis

Results for all the scenarios are presented in Table 6. In general, the net electrical energy and the energy to the mainland are reduced from 2016 to 2030, but all other indicators have the opposite behavior, i.e. the two peak power are increased, as well as the energy import. This mainly attributed to the electrification of the heating sector. The new heat pumps will add an important load to the electric system, and if the heat storage is not sufficient enough, this load will have an elastic behavior. To explore this statement, a sensitivity analysis is conducted by increasing the district heating storage capacity by 1.5, 3, and 6 times. The sensitivity analysis results are presented in Figure 12 to Figure 15. The peak power when exporting to the mainland is not affected by the heat storage size, but the peak power when importing from the mainland is reduced by 400 to 450 kW, when heat storage capacity is at least 3 times greater than in the initial case study. Energy import and energy export curves follow asymptotic reduction. When the heat storage is 6 times greater (than the base case) the reduction is about 0.5 GWh. This indicates that the addition of storage units can effectively reduce both energy import and export. This reduction is about 15% of the total energy import and can play an important role in the efficient utilization of the produced renewable energy for the coverage of island energy needs. When the storage capacity is 6 times greater, the storage unit can provide approximately 18 hr of the average heating load, which is close to 24 hr proposed by [32].

Table 6: Case Studies Results for Samsø

	Reference	**Future A**	**Future B**	**Future C**	**Future D**	**Future E**
Heat Pump Management		HP EMS 1	HP EMS 2	HP EMS 3	HP EMS 3 – Dom HP	HP EMS 4
Peak Power to Mainland (MW_e)	28.7	31.13	31.13	31.13	31.02	31.13
Peak Power from Mainland (MW_e)	4.71	7.47	7.56	7.56	8.13	5.55
Duration of Export (hr/a)	6462	7365	7395	7482	7290	7626
Energy to Mainland (GWh)	65.02	62.75	63.23	62.52	60.08	62.7
Energy from Mainland (GWh)	1.75	3.46	2.95	3.18	3.81	1.75

Net Electrical Energy (GWh)	63.3	59.29	60.28	59.34	56.27	60.95
PV Annual Production (GWh)	1.44	12.3	12.3	12.3	12.3	12.3
WEC Annual Production (GWh)	88.18	87.8	87.8	87.8	87.8	87.8
Total RE	89.6	100.1	100.1	100.1	100.1	100.1
Electricity Demand (GWh)	25.2	25.2	25.2	25.2	25.2	25.2
Electric Vehicles (GWh)	-	5.7	5.7	5.7	5.7	5.7
Electrolyzer (GWh)	-	2.1	2.1	2.1	2.1	2.1
Domestic HP (GWh)	-	-	-	-	3	-
DH Heat Pumps (GWh)	-	7.1	7.1	7.1	7.1	5.64
Total Demand (GWh)	25.2	40	40	40	43.1	38.64
% Import energy/ Demand	6.9%	8.7%	7.4%	8.0%	8.8%	4.5%

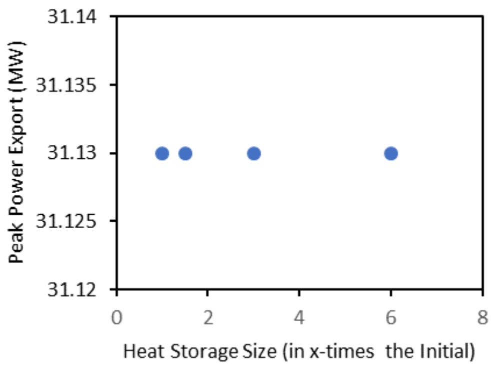


Figure 12: Peak Power Export vs Heat Storage Size

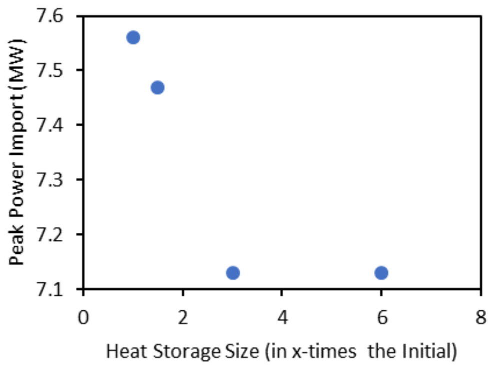


Figure 13: Peak Power Import vs Heat Storage Size

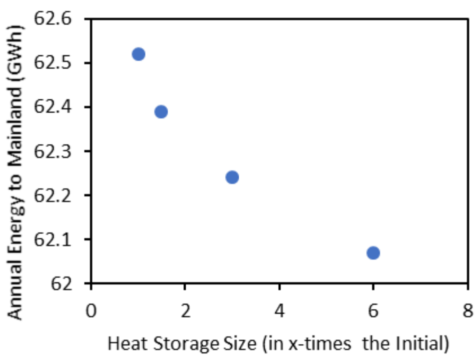


Figure 14: Annual Energy Import vs Heat Storage Size

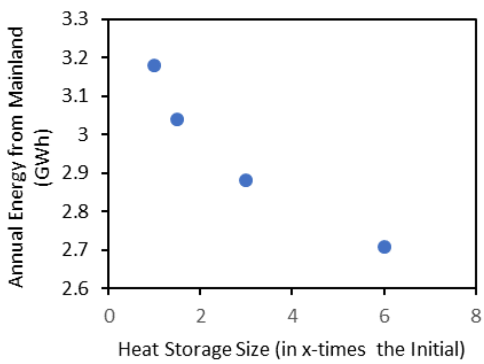


Figure 15: Annual Energy Export vs Heat Storage Size

4.1.2 Grid analysis

The annual power flow simulations (for the reference and for the Future C scenario) revealed that in all cases, the medium voltage ratings for all buses are within acceptable limits. For 2016, the maximum and minimum values have been identified in bus 1018 and it was 15.4 kV and for bus 1011 with value 14.78 kV. For the 2030 case, the maximum voltage has been identified again at bus 1018 with value of 15.34 kV and the lowest at bus 1014 with value of 14.68 kV. Figure 16 shows the locations of the buses with the maximum voltage ratings. The lower voltage buses are on the south/southeast area of the island and the higher voltage bus is located close to the residential and commercial center of the island. This is attributed to the fact that these buses are close both to the interconnection grid from the mainland and the connection points from the offshore wind parks.

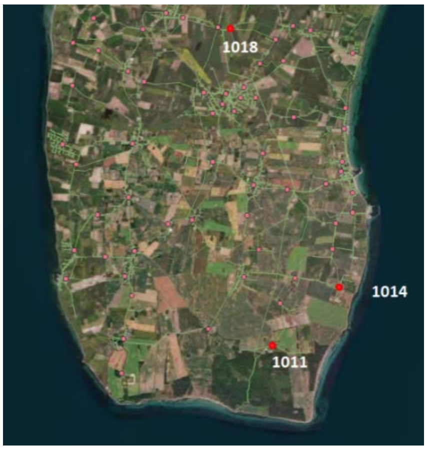


Figure 16: Buses with lowest voltage are located in the south part of the island, while the bus with maximum voltage is located close to the capital.

The voltage variation for a bus for reference and for future scenario C is indicatively presented in Figure 17. The appropriate voltage ratings for the 15 kV network in Denmark are 14.5 kV for the lower limit and 16.5 kV for the upper limit [68]. The proposed interventions will have small interferences in the grid voltage. Their values are lower, nevertheless, this will not affect the grid operation as buses voltages remain bounded inside the acceptable limits. The average grid electrical losses (ohmic etc.) for all scenarios are estimated at 2%. In Figure 18, the electrical production of all the wind and PV systems, along the aggregated electrical demand of the DH systems and electrolyzer for a week and for the Future C scenario, are presented. A detailed view for the first day of this week is presented in Figure 19. The yellow curve presents the aggregated energy demand for all four DH (Heat Pump) systems and forms this polygon-chain looking shape, due to the ON-OFF sequences of the individual heat pumps. Additionally, the import/export curves from the mainland are presented.

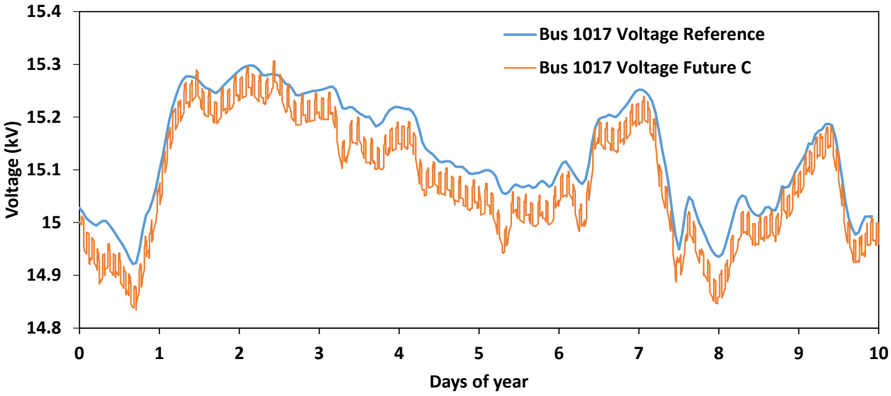


Figure 17: Comparison of Bus 1017 voltage variation for the first 10 days of the simulation, between Reference and Future C scenario.

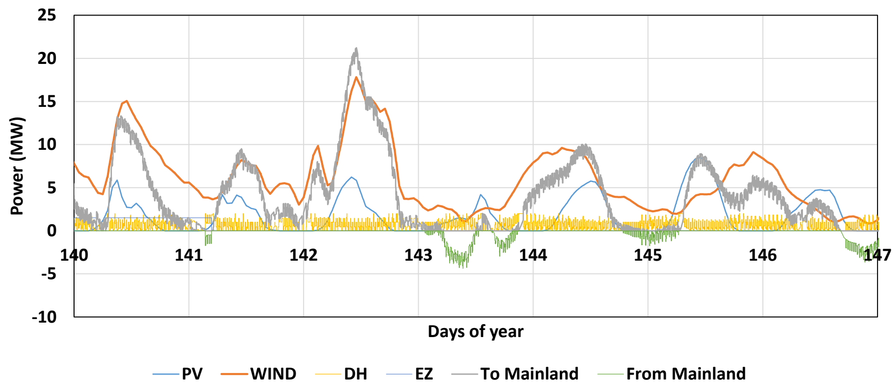


Figure 18: Systems' operation representation for week 20 *of the Samsø grid (Future C scenario)*

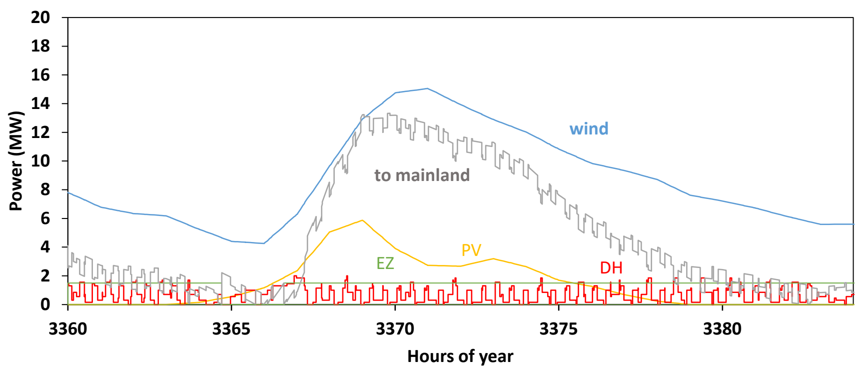


Figure 19*: Systems operation for one day* 140 *of the Samsø grid (Future C scenario).*

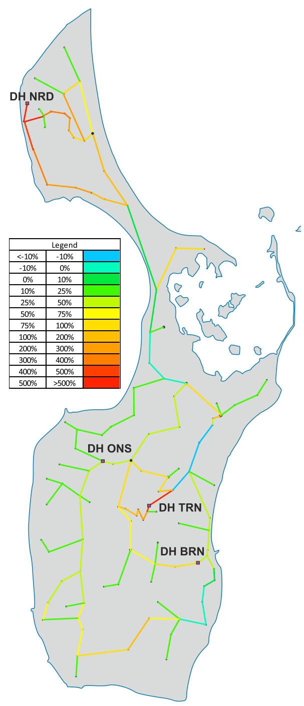


Figure 20: Energy flow variation in power lines (distribution grid) due to the installed heat pumps in the district heating system between the Reference case and Scenario C (In the northern part the grid lines/buses are not in actual position).

As shown in Figure 20, the interventions in Scenario C, have an important impact on the annual energy flow through the grid. In most of the final branches, there is the expected increase due to the increase in the electrical demand due to EV charging (moderate increase with green color). In the neighboring areas of the district heating plants, there is an important increase in the annual energy flow (high increase with yellow and red color) due to the heat pump consumption. In the right main grid line, an important reduction occurs in the annual energy flow (light blue color). This is also attributed to the increase of consumption, and thus local energy production from RES is not transferred through these lines.

The normal everyday operation in Samsø relies on one cable (VST) and the second cable (BEG) is installed only for contingency reasons as operation of both cables might cause grid stability issues. Nevertheless, in this study, both interconnection cables are used simultaneously in all cases. According to this assumption, 47% of energy is exported in BEG and 53% in VST in both current and future scenarios. When energy is imported, both cables are importing the same amount of energy. In terms of power, BEG has low import peak at 2.7 MW in the reference scenario and high export peak at 16.23 MW while KNU has peak import at 14.60 MW and peak export at 19.21 MW. For the future 3 scenario, both cables face more or less the same peaks around 4 MW for import and 16 MW for export, respectively.

4.2 Orkney Results

4.2.1 Energy system analysis

The simulation results of the Present scenario (Table 7) reveals that Orkney covers its energy needs from RES to a great extent as the total annual RE production is 191.73 GWh whereas the corresponding energy demand is 140.41 GWh. Nevertheless, due to the production-consumption mismatch, 12.05 GWh has to be imported from the grid. In the scenario Future A, the newly installed RES decreases the energy import from the mainland by half, but the curtailed energy increases by a factor of three. In scenario Future B, the curtailed energy is almost negligible (due to the extra demand of the interventions), the energy imported from the mainland is considerably higher, but the net electrical energy is still very high. In the scenario Future C, the import and export energy levels are close to the Reference scenario, although the net electrical energy demand is reduced and the curtail is higher. In scenarios Future B and C, the imports are increased due to the non-controllable loads, mostly due to the EVs. Both EZ and DH are controllable loads, as the EZ is in priority to operate with curtailed energy (when available) and when not available, operates with grid energy and the DH operates to charge the heat storage when energy is exported from the island, otherwise it operates to cover the current needs. Two important relative results for each scenario are presented in Table 7 that can reveal the relative impact of the scenarios. These are the curtailed energy to the produced energy from RE and the import energy to demand. As it is shown the best solution in order to reduce curtailment, it is not to add the new demand response loads but the new RES (Future B). If the proposed new RES and demand response loads, are going to be installed, the relative curtail will be the same. On the other hand, in Future B scenario the relative import is considerably increased, while in Future C scenario, the relative import is close to the present scenario. One solution is to investigate the installation of other vRES and not tidal and PV or to further explore the demand response action with heat pumps. The possibility to install heat pumps in houses with demand response in the Eday island, is explored in the next section.

Table 7: Case Studies Results for Orkney

	Present	Future A	Future B	Future C	Future D
Peak Power to Mainland (MW)	30	30	30	30	30
Peak Power from Mainland (MW)	18.4	18.4	29.8	29.5	29.5
Energy to Mainland (GWh)	99.18	121.86	75.39	95.28	94.93
Energy from Mainland (GWh)	12.05	6.405	25.25	15.83	15.92
Net Electrical Energy (GWh)	87.13	115.45	50.14	79.44	79.01
PV Annual Production (GWh)	1.26	10.99	1.26	10.99	10.99
Wind Annual Production (GWh)	177.04	173.18	178.46	176.63	176.91
Wave Annual Production (GWh)	7.06	7.06	7.06	7.06	7.06
Tidal Annual Production (GWh)	4.52	26.99	4.52	26.99	26.99
Total RE production (GWh)	189.88	218.22	191.30	221.69	221.24
Gas Station Energy Production (GWh)	39.72	39.72	39.72	39.72	39.72
Curtailed Energy (GWh)	1.85	5.71	0.43	2.2 6	2.21
Energy Demand Dom (GWh)	140.41	140.41	140.41	140.41	140.41
Energy Demand EZ (GWh)	-	-	4.2	4.2	4.2
Energy Demand EV (GWh)	-	-	13.6	13.6	13.6
Energy Demand DH (GWh)	-	-	8.17	8.17	8.17
Total Energy Demand (GWh)	140.41	140.41	166.38	166.38	166.38
% Curtailed / produced RE	1.0%	2.6%	0.2%	1.0%	1.0%
% Import energy / Demand	8.6%	4.6%	15.2%	9.5%	9.6%

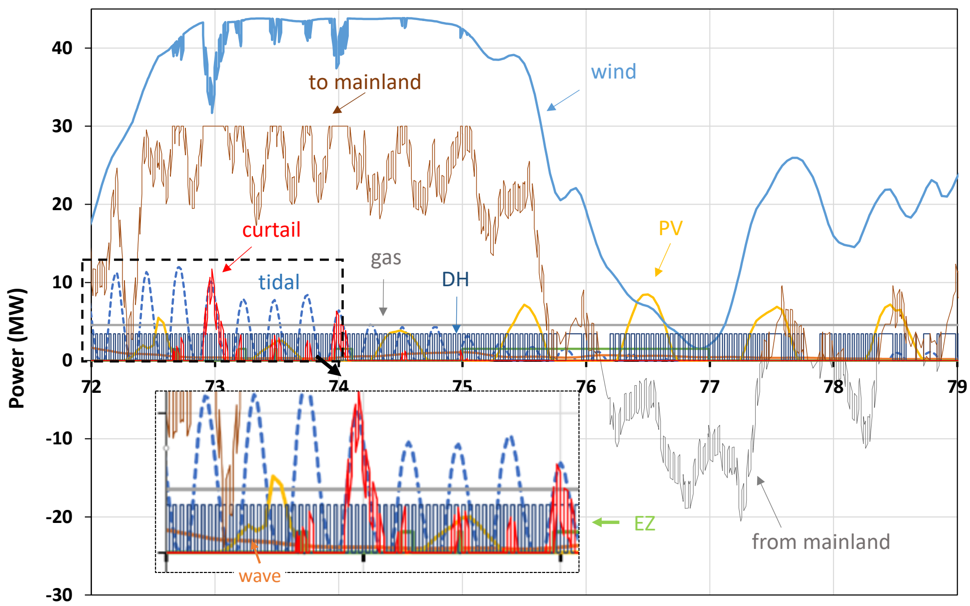


Figure 21: Systems' operation representation for one week of the Orkney grid (Future C scenario).

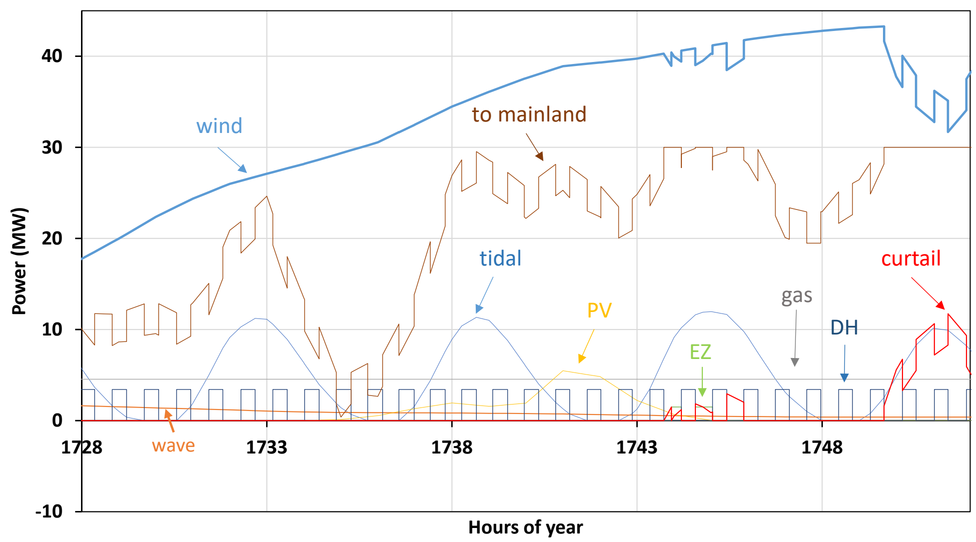


Figure 22: Systems' operation representation day (72) of the Orkney grid (Future C scenario).

In Figure 21 the electrical production of all the RES systems, as well as the electrical demand of the DH system and electrolyzer for a week and for the Future C scenario, are presented. A detailed view for the first day of this week is presented in Figure 22. The red curve presents the curtailed energy (energy that is not produced). As it can be seen from two figures, tidal energy has a predictable energy production pattern and when its production is high, in addition to the high wind energy, curtailment occurs. On the other hand, from day 76 to 78, limited renewable production exists and the required amount of energy has to be imported from the mainland. Finally, at the start of day 76 and by the end of day 77, the district heating (HP) is not operating due to energy import status and it uses the heating storage.

For all scenarios, apart scenario D, the aggregated monthly values for the import/export and curtailed energy are presented in Figure 23.

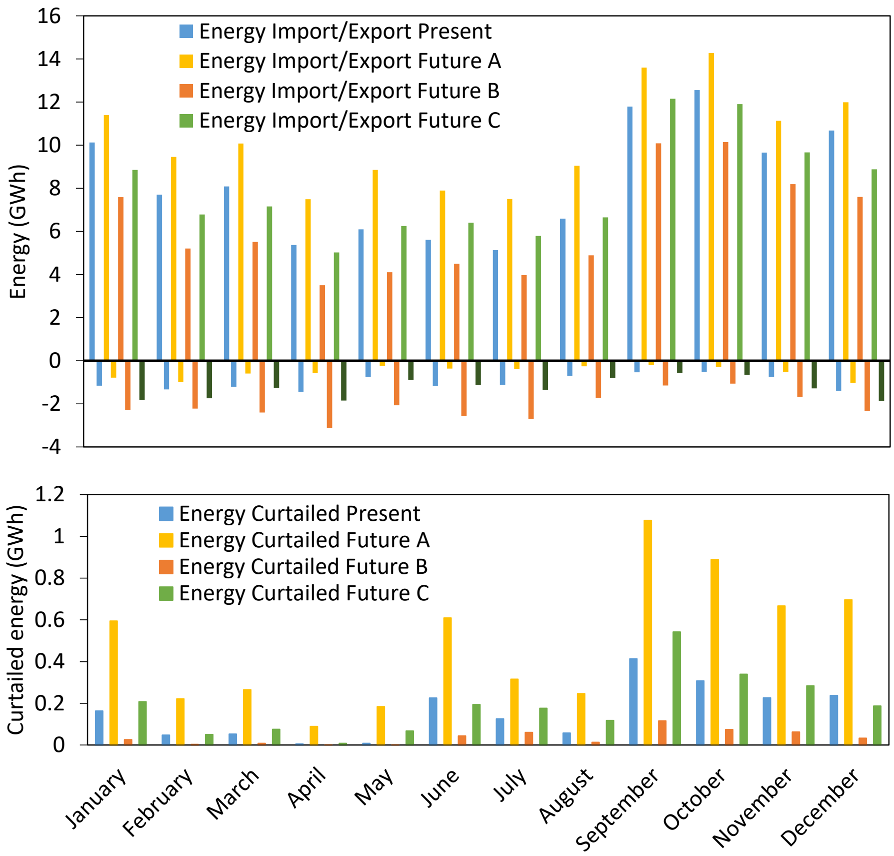


Figure 23: Aggregated Monthly values for energy import/export and expected curtail for the four scenarios.

4.2.2 Power flow analysis of P2H concept at Eday households

In order to reduce curtailed energy for the Future C scenario, the scenario of total electrification of heating has been examined for the island of Eday (Future D). Running the simulation, the results showed that curtailed energy can be reduced by 0.049 GWh (or by 2.2%). This number may have a small impact on curtailment, but it only refers to 85 houses which is 0.76% of the Orkney houses. From energy point of view, this reveals that there is an important margin to increase the P2H actions. The results per house type are presented in Table 8.

Table 8: Eday Power to Heat Results per house type

Number of rooms per house	2	3	4	5	6
P2H Energy (MWh)	2.85	3.96	4.92	8.29	9.32
P2H from Curtail (MWh)	0.23	0.38	0.52	1.14	1.23
Heating Needs (MWh)	6.20	9.30	12.40	15.50	18.60
Heating Needs from Curtail (MWh)	0.46	0.75	1.04	1.50	1.60
Heating Needs through Storage (MWh)	0.16	0.30	0.44	0.74	0.70

From Table 8 and for all houses, the energy demand due to the P2H technology will be 0.42 GWh, meaning that 11.5% of the P2H energy will be from curtailed energy. The curtailed energy will be able to cover an average of 8.55% of the heating needs. Storage plays an important role, as provides from 35% to 50% of the heat produced by curtailed energy with an average of 43.3%. The 5-Room house type has the higher exploitation of storage as its heat storage has the same capacity as the 6-Room house type, but lower demand. The behavior of the five house types for three days is shown in Figure 24. A closer view to the P2H solution and the heat and electrical power flow during a certain period when three curtailment events occur are shown in Figure 25.

The heat pump interventions have a small impact on the 11 kV distribution grid of the island. The lower voltage level in the worst-case scenario is 10.66 kV in a bus in the northern part of the island and is in the acceptable limits [69]. On all the buses, the higher voltage was 11 kV.

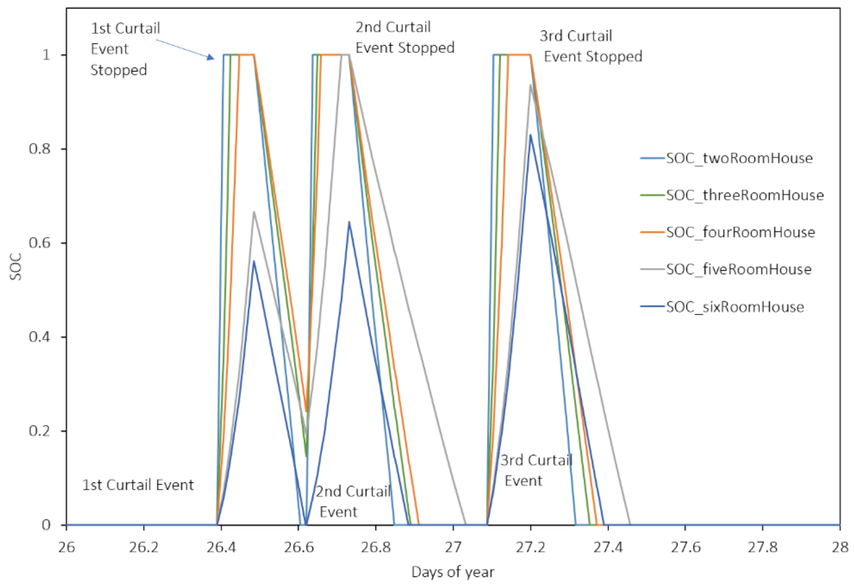


Figure 24: Behavior of the five houses types for three days.

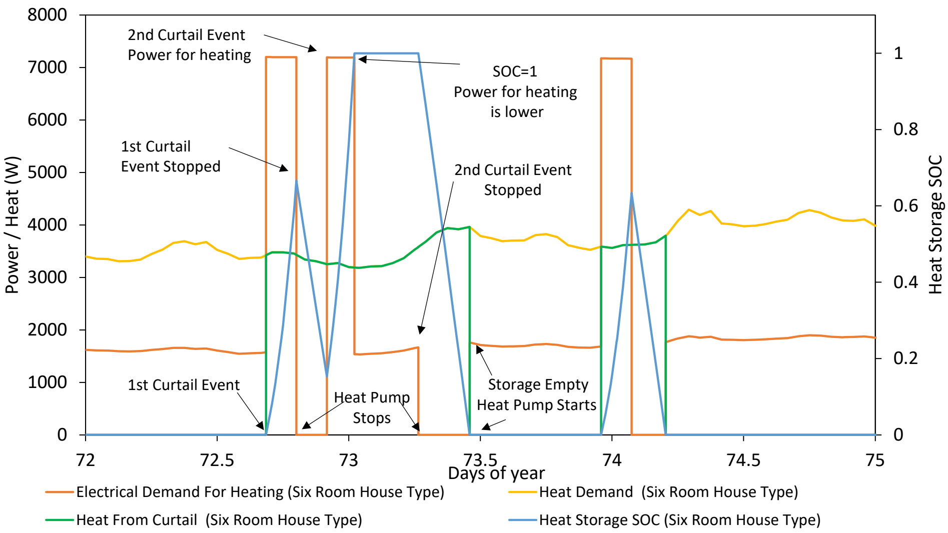


Figure 25: A closer look to the HP operation and storage. During the period, 3 curtail events take place.

A possible drawback of the P2H solution lies in the fact that a very high energy demand is calculated, when there is no curtailment. The usage of P2H solution when there is no curtailment may have a negative impact on the overall islands' autonomy by importing large amounts of energy, or even limited power supply from the cable. Installing larger capacity heat storage or using another technology (e.g. biomass), when there is no curtailment, are two possible solutions, but they have to be evaluated under a techno-economic perspective.

4.3 Results and study uncertainties

This work features a limited number of assumptions and uncertainties, and in this paragraph, the most important parameters that can import uncertainties are discussed. A basic assumption that is made concerns the projection of future situation in power production and consumption using data and information from the current period 2016-2020. This fact reflects a deviation from the reality that cannot be measured or evaluated since the corresponding forecasting models on power generation/consumption also carry an uncertainty that cannot be estimated at this moment. Another aspect that prevented a valid error analysis is that the given input data that was stem from different but coherent sources is not accompanied with uncertainty values.

Moreover, as concerns curtailment events, for Orkney, the analysis was based only on arbitrary but realistic technical assumption (power limit 30 GW), in fact, there are also various technological and non-technological reasons that provoke curtailments. It is roughly estimated that the actual curtailed energy may be at least 50% higher. Other deviations that may exists in grid level are associated to the actual power consumption that is distributed in the nodes/buses with a relatively uniform way. Actual consumption data does not exists in each MV/LV transformer and the electricity consumption in remote areas of the islanding regions is limited and frequently zero, as these areas may have few consumers.

5 Conclusions

In this work, innovative energy production, storage and management technologies using full-scale grid dynamic simulation methods in Modelica using PowerSystems Library, have been modeled and assessed, using real data for grid representation, along with realistic and innovative demand and supply assets.

Samsø produces a large amount of electrical energy which most of the time is being exported to the mainland, with a small amount being imported. Simulation results showed, on grid level, that the system losses are the same as before and around 2% the proposed interventions, and grid voltage levels are within the local transmission code limits. On aggregated level, and for the proposed electrification scenario, reduces export by 5 GWh but it increases import by 2 GWh One possible solution lies in increasing available storage, i.e. a district heating thermal storage, which high capacity can play an important role in electrical grid import/export balance and can reduce import peak load.

As concerns Orkney, on an aggregated level, curtailment is reduced by 77% (1.4 GWh) after the proposed interventions but import increases by 13 GWh.. To explore further the curtailment reduction possibilities, Eday island in the Orkney cluster is chosen to be simulated for fully heat electrification through local heat pumps. On a grid level, the impact (e.g. voltage and loses) is not so high and it can cope with the extra burden and on an aggregated level, the results show that heating needs can be covered by curtailed energy up to 10% in some cases.

100% RES in islanding areas is a feasible goal, but this cannot be achieved at the examined topologies, at least currently, without losing or exporting a considerable amount of energy.. To this extent, for future studies, the inclusion of electrical storage in various areas on an island can be tested and simulated in order to assess the grid impact, the impact in curtailment and on energy import/export figures. In addition, heat pumps with or without heat storage can be further deployed in all islanding premises out of the district heating network. Advanced models regarding the EV's integration (Grid-to-Vehicles-to-Grid), considering cost and energy availability will be an important feature for future work. Finally, analytic techno/economic and environmental evaluations of the proposed solutions can be applied in order to estimate the benefit of each intervention.

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7 Abbreviations

HP	Heat Pump
GT	Gas Turbine
WT	Wind Turbine
EZ	Electrolyzer
DR	Demand Response
EMS	Energy Management System
TD	Tidal Turbine
WV	Wave Turbine
PV	Photovoltaic
SC	Solar Collector
EV	Electric Vehicle
P2H	Power to Heat
SoC	State of Charge
ST	Storage
EMEC	European Marine Energy Center
PEM	Proton Exchange Membrane

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