Empowering local renewable energy communities for the decarbonisation of the energy systems

D1.3 – Decarbonization scenario assessment for the study cases

08 June 2023

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Description	This document presents the assessment for the LocalRES pilots to identify the least-cost solutions to enable a faster energy transition and decarbonization, reinforce Renewable Energy Communities (REC) and cover future energy demand of the use cases. This is linked to the main objective of RECs, considering a sector coupling approach and grid infrastructure needs, and exploring the increase of self-sufficiency by local renewable energy sources (RES) and maximisation of the system flexibility leveraged on energy storage. In addition, the identification of bottlenecks, blackout events, optimal solutions and recommendations are provided.				

Date	Version	Author	Comment
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Executive summary

LocalRES project will deploy innovative local energy systems driven by Renewable Energy Communities (RECs) and with a sector coupling approach, for a socially fair energy transformation that puts renewable energy into the hands of communities and people. The systems will be able to interconnect and co-optimise the operation of different energy vectors (e.g. electricity, heating), maximise the RES contribution and enhance the energy system flexibility and supply security.

This document aims to reflect future possible scenarios in the four LocalRES demonstration sites (Kökar, in Finland; Berchidda in Italy; Ispaster, in Spain; and Ollersdorf, in Austria) for the development of the energy communities and foresee how the local resources as well as flexibility measures will be needed. Therefore, it assesses the energy transition and a decarbonization perspective of LocalRES pilots under the 2030 horizon. Moreover, the content focuses on the energy sector due to the nature of the project,

Balmorel is the open-source modelling tool which will be used to assess the scenarios. This modelling tool optimizes energy production investments in different scenarios by minimizing the total investment and operational costs of the systems, allowing to find the least-cost solution for the energy transformation in each scenario.

Three scenarios are analysed within the LocalRES project in each pilot. The goal of these scenarios is to define different possibilities in the long-term perspective (2030) about how a potential energy community constituted by the whole village of the demo sites can perform and support decarbonization in the village. In this analysis, the impact of flexibility measures such as demand-side management (DSM), smart charging for electric vehicles (EVs), energy storage, as well as the use of HPs, combined heat and power (CHP), local VRESs, hydrogen production, blackout prevention, and reduction of the dependence grid are explored.

The methodology to create the future energy scenarios for the energy demand and supply for LocalRES pilots follows the next steps:

1. Deployment of the overall structure of the energy model under Balmorel energy tool
2. Integration of the future electricity prices and future transmission line connection of the pilots to the national grid
3. Integration of the flexibility measures: demand side management, energy storage, HPs, CHP systems and electric charging in EVs.
4. Creation of a techno-economic database of energy supply technologies.
5. Calibration of the base year and future demand heat projections
6. Implementation of the energy and technological constraints
7. Scenario implementation for future decarbonization and energy transition to assess the scalability of the flexibility measures
8. Scenario evaluation.

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In general energy communities can support to the decarbonization of community due to the most efficient use the local energy resources supporting by flexibility measured to address properly the highest electrification of the system.

The replacement of the fossil fuel boilers and ICE vehicles by the ones driven by electric can support in the reduction of the direct local CO_2 emissions. However, an increase of the electrification can have the rebound effect increasing indirect CO_2 emissions. In this sense, it is important accompany the policy of increase of the use of electric equipment (e.g., HPs, EVs) together with an additional renewable install capacity to mitigate the possible increase on the indirect CO_2 emissions.

In addition, the results show that flexibility measures as the DSM, smart-charging or the use of storage allow reducing the needs of the effective capacity of the transmission line in a significant way, hence allowing the community to be more resilient to the possible lack of power from the transmission line, and even to use this flexibility to provide services to the electric system operator. Moreover, enough capacity of the transmission line to ensure electricity trading is fundamental to achieve the electric energy balance of the community. However, DSM can produce high fluctuations in the heating profile due to the high penetration of HPs, and smart-charging can produce a saw-tooth effect in the overall electricity consumption profile

A high increase of electric batteries is necessary to prevent the communities against blackout from the transmission lines. This additional capacity of electric batteries not only mitigate the blackout event also can increase the electricity balance and get a more effective electricity exchange with the national grid to generate revenues to the community.

Photovoltaics (PV) is the most relevant technology for electricity production, however wind production can play an important role. A seasonal mismatch between local production and consumption can occur (specially with PV). This situation can produce curtailment in these systems during the summertime because the electricity surplus could not be consumed, exported to the national grid, or stored.

Base load electricity production, and in particular biomass Combined Heat and Power (CHP), can be very relevant and fundamental to achieve the full independence from the national grid of an energy community (energy island). This technology can be combined with other ones such as PV panels, and energy storage play a fundamental role to achieve the energy balance.

The location of the infrastructure to generate hydrogen to decarbonize transport modes in the regular transport routes (e.g., ferry routes and scholar bus routes) has an impact on the electricity consumption and production. This infrastructure can make grow exponentially the electricity demand in the communities in case of relevant hydrogen needs.

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List of acronyms and abbreviations

°C	Celsius degree
BK-SC	Blackout scenario
CHP	Combined Heat and Power
CO_2	Carbon dioxide
COP	Coefficient of performance
DH	District heating
DHW	Domestic hot water
DSM	Demand Side Management
e-	Electrons
EB-SC	Energy Balance Scenario
EI-SC	Energy island Scenario
EL-SC	100% Electrification Scenario
EENS	Expected Energy Not Served
EU	European Union
EV	Electric vehicles
e-vehicles	Electric vehicles

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FLH	Full-load hours
Grid2V	Grid to vehicle
GWh	Gigawatt hour
H+	Protons
H_2	Hydrogen
H2T-SC	Hydrogen in Transportation Scenario
HP	Heat pumps
ICE	Internal-combustion engine
km	kilometre
km^2	Square kilometre
kW	kilowatt
kWh	kilowatt hour
kWp	kilowatt peak
Li-Ion	Lithium ion
LPG	Liquid petroleum gas
m^3	Cubic meter
MEC	Microbial electrolysis cells
MW	Megawatt
MWh	Megawatt hour
N/A	Not Applicable
NECPs	National Energy Carbon Plans
NO_x	Nitrogen oxides
O_2	Oxygen
pkm	passenger-kilometre
REC	Renewable Energy Community
Ref-SC	Reference Scenario
TD-SC	Transport Decarbonization Scenario
TSO	Transmission System Operator
vkm	vehicle-kilometre
V2G	Vehicle-to-grid

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1/ Introduction

LocalRES project will deploy innovative local energy systems driven by RECs and with a sector coupling approach, for a socially fair energy transformation that puts renewable energy into the hands of communities and people. The systems will be able to interconnect and co-optimise the operation of different energy vectors (e.g. electricity, heating) , maximise the RES contribution and enhance the energy system flexibility and supply security. The focus is on the RECs as main actors for leading the structural change in the current energy system towards the decarbonisation of the local energy systems based on an integrated multidirectional flow approach and prosumers, allowing to maximize the replicability and upscale the potential of the decentralized solutions developed in the project. The LocalRES solutions promote a secure, sustainable, competitive, and affordable energy supply for everyone.

This document presents the **assessment for the LocalRES pilots to identify the least-cost solutions, by using Balmorel optimization model,** to enable a faster energy transition and decarbonization, reinforce RECs and cover future energy demand of the demo sites pilots. Flexibility measures implemented under the scenarios are based on the services identified in deliverable D1.2, being the following ones implemented under the modelling tool: *Building heating optimization*, *Heating as a service*, *Operation of a DHN with RES*, *P2H (and H2P)*, *Collective Peak shaving*, *Blackout strategies*, *Demand response*, *V2G services* and *Smart Charging*. These services are clustered depending on the specification of each scenario. This is linked to the main objective of RECs in terms of self-consumption, interaction with the grid and reduction of CO_2 emissions by considering a sector coupling approach and grid infrastructure needs, and exploring the increase of self-sufficiency by local renewable energy sources (RES) and maximisation of the system flexibility leveraged on energy storage. In addition, the **identification of bottlenecks, blackout events, optimal solutions and recommendations** are provided.

1.1. Purpose & Objectives

This document aims to **reflect future possible scenarios for the development of the energy communities and foresee how the local resources as well as flexibility measures will be needed**. Therefore, it assesses the energy transition and a decarbonization perspective of LocalRES pilots under **2030 horizon**. This includes energy demand for the overall sector as well as electric and heat production from local sources. **Balmorel model tool** (Wiese et al., 2018) is used for this purpose, that allows to reflect future scenario and dependence from the national grid including blackouts as well as flexibility measures such as demand side response or smart charging for EVs.

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1.2. Scope of the work

The scope of this deliverable is limited geographically to the four demonstration locations: Kökar in Finland, Berchidda in Italy, Ispaster in Spain, and Ollersdorf in Austria. Moreover, the content focuses on the energy sector due to the nature of the project, and Balmorel modelling tool will be used to assess the scenarios. However, the evaluation framework included in this document will explore the energy transformation of the pilots in 2030 horizon when the energy communities are fully established.

1.3. Relation to other activities of the project

Apart from providing decarbonization scenarios assessment for the pilots, this deliverable presents specific information for other tasks under WP1, but also to WP3 and WP4 to develop their activities.

Table 1: Relation of current report to other deliverables

Deliverable	Relation
D1.2 Definition of the Use Case	Flexibility measures are based on the services defined under this deliverable.
D1.4. - Cost-benefits analysis (Methodology and results)	Related to the calculation of the cost benefit analysis indicators providing data and information from the data collection and results developed in Task 1.3.
D1.5. - Business models shift from passive consumers to RECs	The results from the scenarios included in Task 1.3 will help to frame business models in the LocalRES pilots.

Table 2: Relation of current report to other tasks

Deliverable	Relation
Task 1.4. - Cost-benefit analysis of project Use Cases	The selection of the indicators as well as the data collection and results will support the framing and the calculation of the cost benefit analysis indicators
Task 1.5. - Business model development	Data collection and results from the scenarios in this task will contribute to frame the business model discussion among the stakeholder in the pilots
Task 4.1. - Demonstration actions KPIs definition and baseline studies	Data collection for the calculation of the KPIs were coordinated together. They will include similar information related to technical aspects.
Task 2.3. - LocalRES database construction	Data transfer for the construction of the LocalRES database

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2/ Methodology

Figure 1 shows the overall view of the methodology used to assess the future scenarios for the development of the energy communities. In this context, Balmorel modelling tool has been used to analyse how flexibility measures as well as local energy production sources can contribute to the targets established for the LocalRES pilots.

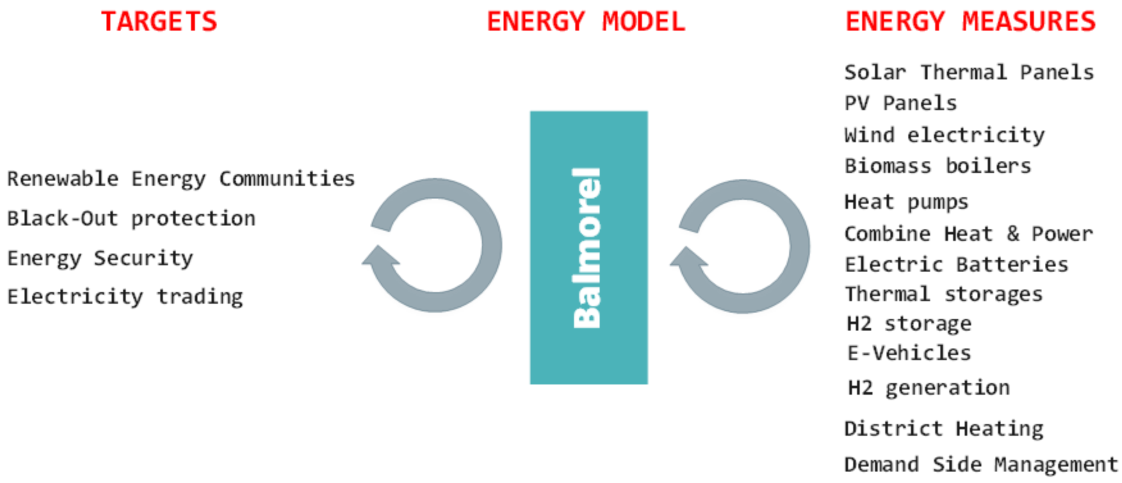

Figure 1: Overall view approach

The methodology to create the future energy scenarios for the energy demand and supply for LocalRES pilots follows the next steps:

1. Deployment of the overall **structure of the energy model** under Balmorel energy tool;
2. Integration of the future **electricity prices** and future **transmission line** connection of the pilots to the national grid;
3. Integration of the **flexibility measures**: demand side management, energy storage, heat pumps (HP), CHP systems and electric charging in EVs;
4. Creation of a **techno-economic database** of energy supply technologies;
5. **Calibration** of the base year and future demand heat projections;
6. Implementation of the **energy and technological constraints;**
7. **Scenario implementation** for future decarbonization and energy transition to assess the scalability of the flexibility measures;
8. **Scenario evaluation**.

In the following subsection, the Balmorel modelling tool, flexibility options and future electricity -prices methodology are described to provide a more detailed view.

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2.1. Balmorel modelling tool

The overall goal of the LocalRES project is to support the development of energy communities around Europe. For this purpose, the open-source energy system modelling tool Balmorel (developed initially for Baltic Sea Region (DTU)) (Wiese et al., 2018) has been used to assess the future scenarios of these energy communities in the LocalRES pilots: Berchidda, Ispaster, Ollersdorf and Kökar. Balmorel is an **open-source modelling tool for optimizing energy production investments in different scenarios**. It is a model that **minimizes the total investment and operational costs of the systems allowing to find the least-cost solution for the energy transformation in each scenario modelled under this tool**. It considers the balance of supply and demand of electricity and heat, reserve power demand, possible investment in new production and transmission capacity, power plant and transmission line capacity restrictions and efficiencies, CHP production limits as well as the assessment of several flexibility options, such as, demand side management (DSM) or smart charging of EVs.

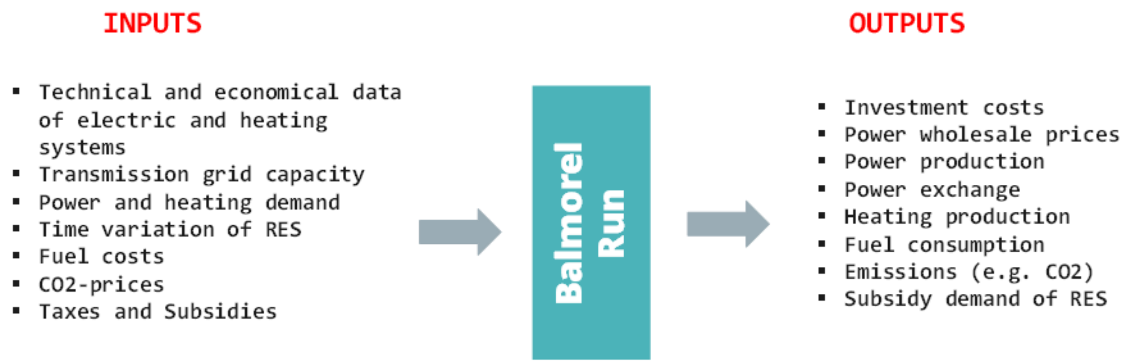

Figure 2: Main Input and output parameters of modelling tool Balmorel (own illustration based on (Wiese et al., 2018)

The model has already been tested for various analyses of the power and heat markets at a regional and at a country level, e.g., in Scandinavia and other European countries as well as in other countries such as China (Wiese et al., 2018). As the geographical scope is flexible, this model allows simulations for cities, regions and islands as well. For this project, **the model has been calibrated and adapted for the electricity and heat system for the four pilots**.

2.2. LocalRES- Flexibility measures

2.2.1. Power to Heat - Heat pumps

Heat pumps (HPs) are mechanical-compression cycle refrigeration systems. A heat pump uses external power (electricity) to accomplish the work of transferring energy from a colder heat source to a warmer heat sink (J. Bundschuh and G. Chen, 2014).

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These systems can contribute to integrate the expansion of variable renewable energy sources (vRES) e.g. wind, photovoltaic or run-of-the-river hydropower, making better use of temporary renewable electricity surplus with the sequence overall CO_2 reductions (D. Patteeuw et al., 2015). Heat pumps can be implemented in a cost-effective way where reductions of costs are driven by the substitution of fossil fuels, better use of invested capital, lower needs for auxiliary technologies, higher efficient operation of thermal power plants and the use of existing district heating (DH) infrastructure (K. Hedegaard et al., 2012).

Small-scale HPs for building application (around 6 kW) have higher efficient conversion rates, competitive prices, lower operation and maintenance costs and a long lifespan compared to other combustion-based heating systems. However, these systems have a high start-up cost, are difficult to install and some of the fluids used for heat transfer are of questionable sustainability (UK Renewable Energy Hub, 2020).

2.2.2. Combined Heat and Power – CHP

CHP allows to generate electricity and provide useful thermal energy by capturing the heat that would otherwise be wasted. This heat can be used for several applications, such as space heating. This technology has a wide capacity range, thus, it can be implemented to a wide variety of applications, be driven by different type of fuels e.g., biomass or natural gas, dimension-wise from individual facilities or buildings to larger-scale systems, such as DH networks. Moreover, while 35-60% of the fuel used in conventional power plants is converted to useful power, fuel efficiency levels can rise over 80% in CHP due to heat utilization (EPA, 2021; Siemens Energy, 2021).

From an environmental perspective, this technology has a positive impact because the lower fuel combustion implies a reduction of greenhouse gas emissions such as carbon dioxide (CO_2), as well as other air pollutants like nitrogen oxides (NO_x) and sulphur dioxide (SO_2) (EPA, 2021).

The installation of CHP plants can provide several benefits (EPA, 2021):

- *Reduced energy costs:* CHP reduces energy bills due its high efficiency along with the possibility to produce electricity on site.
- *Avoided capital costs:* CHP can often reduce the cost of replacing heating equipment.
- *Protection of revenue streams:* CHP can allow facilities to continue operating in the event of a disaster or an interruption of grid-supplied electricity.
- *Less exposure to electricity rate increases:* due to a lower exposure from electric network. In addition, a CHP system can be configured to operate on a variety of fuels allowing to the facility the possibility to switch the fuel to hedge against high fuel prices.

2.2.3. Power to Vehicle – EVs

Vehicles running on fossil fuels are being replaced by EVs, increasing the need for production units in the electricity sector. These new production units must then cover the new demand at the required times, which influences investment decisions. However, the specific demand requirements

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of EVs (e-vehicles) are highly dependent on the chosen charging schemes (Gunkel et al., 2020). Three main charging schemes can be considered:

- *Passive charging:* This type of charging is unidirectional (grid to EVs) and forces charging the batteries of e-vehicle according to a fix profile
- *Smart charging:* This type of charging is unidirectional (grid to EVs) and optimizes charging batteries of EVs considering electricity cost and available electricity capacity from the grid.
- *V2G:* Vehicle-to-grid, this type of charging is bidirectional (grid to EVs and EV to grid) and optimizes the charging process of batteries in the EV as in the *smart charging* type. However, it further allows energy to flow back to the grid when price signals of the system indicate profitable hours; i.e. the ones with the highest prices, or when the system needs to be supported to cover the electric demand.

2.2.4. Power to Gas - Hydrogen electrolyser

Hydrogen production from renewable power in combination with hydrogen storage can provide long-term seasonal flexibility to the system. Electricity is used in an electrolyser to produce hydrogen and oxygen from water. Then, hydrogen is stored for electrical applications, and it is re-electrified, e.g. via fuel cells (EASE, 2020). Hydrogen has a high flexibility, being able to be used not only in the power sector, providing balancing between demand or supply, but also as feedstock for H_2-vehicles or H_2-boats. There are four main electrolysis methods: Alkaline Water Electrolysis (AWE), PEM (Polymer Electrolyte Membrane) water electrolysis, Solid Oxide Electrolysis (SOE) and Microbial Electrolysis Cells (MEC) (M.N. Nandanwar et al., 2020).

Under the scope of LocalRES project, Polymer electrolyte membrane (PEM) electrolyser is considered. PEM water electrolysis is attained by pumping water to the anode, where it is split into oxygen (O_2), protons (H+) and electrons (e-). The protons travel via a proton-conducting membrane to the cathode side. The electrons exit from the anode through an external power circuit, providing the driving force (cell voltage) for the reaction. At the cathode side, the protons and the electrons re-combine to produce hydrogen (M.N. Nandanwar et al., 2020).

PEM water electrolysis has great advantages such as compact design, high current density, high efficiency, fast response, small footprint, operation temperatures between 20 to 80°C and the production of ultrapure hydrogen and oxygen (N. Nikolaidis and A. Poullikkas, 2017). Additionally, balancing PEM electrolysis plants is very simple, which is more attractive for industrial applications (S.S. Kumar and V. Himabindu, 2019).

2.2.5. Demand-Side Management – DSM

Heating energy systems are designed to satisfy heat peak load, which makes DSM one of the key elements for future energy grids. This energy control is deployed at customer side allowing to reduce the peak load. This control strategy is done by switching part of the heat load during peak period to other periods, reducing the fluctuations during heating peaks and valleys.

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This technology is especially interesting when implemented in HPs, as the load can be adapted to electricity price changes, or to other targeted incentives, either internal or provided by a third party or the electric market (Kirkerud et al., n.d.). Furthermore, active participation of electricity consumers in an energy community in demand response may provide much needed flexibility to the energy system for integrating increasing shares of vRES (Yin et al., 2016).

2.2.6. Energy storage

Energy storage can support energy systems to balance demand and supply on different temporal basis. In addition, these systems could allow to improve the overall energy efficiency as well as reducing the peak demand, the energy consumption, the CO_2 emissions, and the overall costs. Three types of energy storage are being considered in LocalRES: thermal storage, electric batteries, and hydrogen storage.

THERMAL STORAGE

Hot water energy storage is a mature, cheap and well tested technology used in large-scale projects in Europe and all over the world (Danish Energy Agency, 2020). A heating device produces hot water outside or inside an insulated tank, where it is stored for a short period of time (a couple of days maximum). The amount of energy stored depends on the hot water temperature and on the tank's volume (EASE, 2020).

Solar energy and HPs are increasingly being used to produce hot water with high efficiencies. Other energy sources like electricity, gas, heating oil or wood are also applicable. In general terms, this technology does not have local environmental impact. The small-scale thermal storage can ease shifting the thermal load storage taking advantages of the cheaper electricity prices during the off-peak periods. This shift of the thermal load curve allows to reduce the size of some equipment with consequent reduction of investment costs. Although, the capacity of this thermal storage by consumer is small, the overall installed capacity can be very large due to the high number of installations within a community (EASE, 2020).

ELECTRIC BATTERIES (LI-ION BATTERY)

A Li-Ion Battery System is an energy storage system based on electrochemical charge/discharge reactions that occur between a cathode, that contains lithium metal oxide, and an anode that is made of a carbon material or intercalation compounds. The electrodes are separated by porous polymeric materials which allow an electron and ionic flow between them and are immersed in an electrolyte that is made up of lithium salts, e.g., LiPF6, dissolved in organic liquids. When the battery is being charged, the lithium atoms in the cathode become ions and migrate through the electrolyte towards the carbon anode where they combine with external electrons and are deposited between carbon layers as lithium atoms. This process is reversed during the discharge process (EASE, 2020).

Due to their high scalability and flexibility in power and energy, Li-Ion batteries are used in a large variety of applications (Danish Energy Agency, 2020):

- *Peak load reduction* in power systems.
- *Promote renewable integration*, e.g., time or load shifting of PV power from day to night.
- *Provide transmission congestion relief* to reduce the loads in the transmission and distribution systems, helping them to reduce expensive upgrades of the transmission and distribution networks.
- *Provide primary control reserves* for frequency regulation.
- *Improve network reliability* by reacting immediately after a contingency. For example, maintaining stability in the power system until the operator has re-dispatched production, or supporting black-starting capability of the distribution grids
- *Enhancing the power quality and reducing voltage deviations* in distribution networks.

GAS STORAGE – HYDROGEN

Hydrogen storage in pressurized tanks is a system for small and medium scale storage. Hydrogen pressure tanks have several advantages such as the capability of hydrogen ti be stored for relatively long periods without losing significant energy content. .

There are three main problems when trying to compress and store hydrogen in tanks. The first difficulty is the integrity of the materials; hydrogen pressure tanks endure a high number of cycles with pressures (in the range from 50 bar to 1,000 bar) and temperatures (which arise when compressing the hydrogen in the tank). This causes the materials of the tank to be heated from inside generating critical damages in case that temperature exceeds certain levels. (J. Andersson and S. Gronkvist, 2019). The second problem is hydrogen embrittles, which is a process in which metals, like steel, react with hydrogen. This makes them brittle and susceptible to cracking (Danish Energy Agency, 2020). The third problem is hydrogen permeation, which takes place when hydrogen molecules, due to their small size, go through the walls. This can produce a pressure drop inside the tank, as well as a decrease of the stored hydrogen in it (E.D. Rothuizen, 2013).

2.3. Electricity prices

Future national electricity prices are estimated based on the EU28-Balmorel model (Wiese et al., 2018). This model optimizes overall costs in the electricity sector for each EU country following the implementation of their National Energy and Climate Plans (NECPs) (European Commission, 2022) taking into account that this model only estimates the electricity prices in 2030. Figure 3 shows the main overview of the EU28-Balmorel model. It considers two main assumptions:

- The planned power capacities by technology type (e.g., PV, Wind or Biomass) will be deployed in 2030 in each country according to the NECPs.
- Flexibility measures are used to balance possible mismatches between electricity demand and supply.

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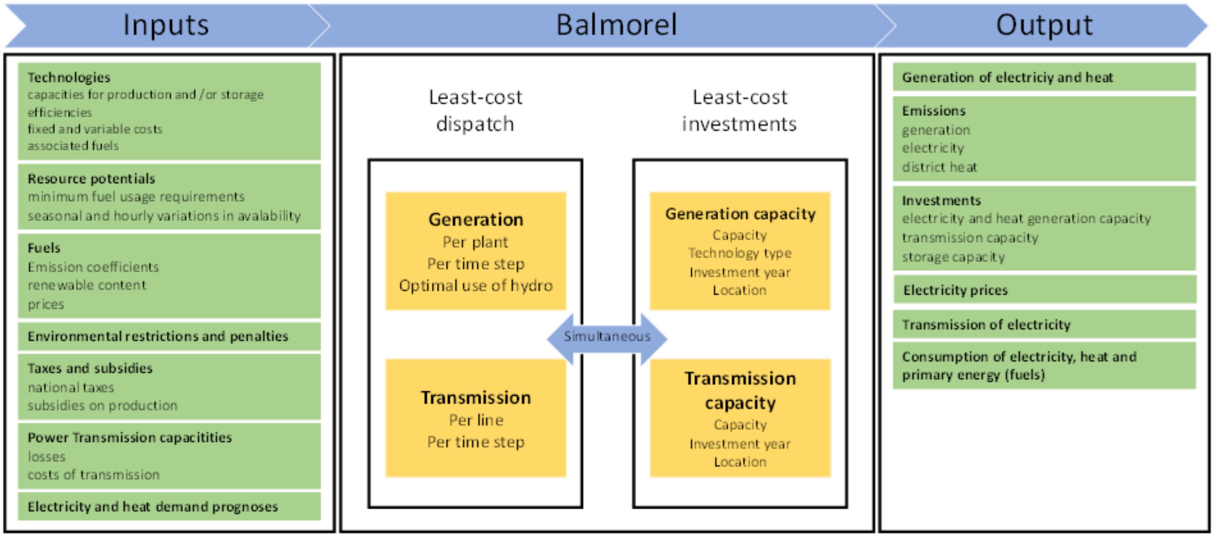

Figure 3: Overview of the EU28-Balmorel Model for electricity prices

Planned power capacities in countries are based on NECPs and included as fix exogenous parameters in 2030, while the model can choose endogenously the optimal set of flexibility measures to meet hourly demand by optimizing overall cost. The flexibility measures considered in the model are, additional gas-fired technologies (gas turbines, combine cycles and steam turbines), HPs, electricity batteries and cross-border electricity exchange between countries using transmission networks.

Additional aspects, such as decommissioning of the current power plants due to their lifetimes, policies like phasing out nuclear power in Germany, fuel availability, fuel prices, CO_2 emission prices, improvement of the technology efficiencies and reduction of costs for future power plants, are considered. This also includes limitations in the investments for future flexibility measures including the use of hydro reservoirs and other storage systems, electric power distribution losses cross-border transmission losses or interest rate for new investments.

The model provides detailed technical results such as hourly energy production by technology or required additional capacity to be installed. Furthermore, results can be aggregated, filtered, and processed to yield an additional level of insight, e.g.:

- **Unit's profitability** by determining revenues and direct costs.
- **Stakeholders economic decomposition of costs and prices**, particularly when comparing two or more different scenarios.
- **Total costs and benefits** from alternatives scenario.
- **Sensitivity analysis results** obtained from the variation of some parameters.

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3/ Kökar demo case

3.1. Overall pilot description

Kökar is a small archipelago village of Åland Islands with a total area of 2,101 km^2, of which 63.6 km^2 are land area and the rest is sea (Municipality of Kökar, 2022), as Figure 4 shows. The distance to Kökar from the mainland is about 50 km travelling by ferry. Kökar is perceived as a remote place because it takes 2.5 hours to travel there by ferry (Vainio, 2020). Kökar community includes several basic services such as a library, a school, a kindergarten, health services and a nursing home. The main economic activities are tourism, fishing, shipping trade, agriculture, bakery, and building (Municipality of Kökar, 2022), being tourism the most important one with a contribution € 1.9 million to the local economy (Vainio, 2020).

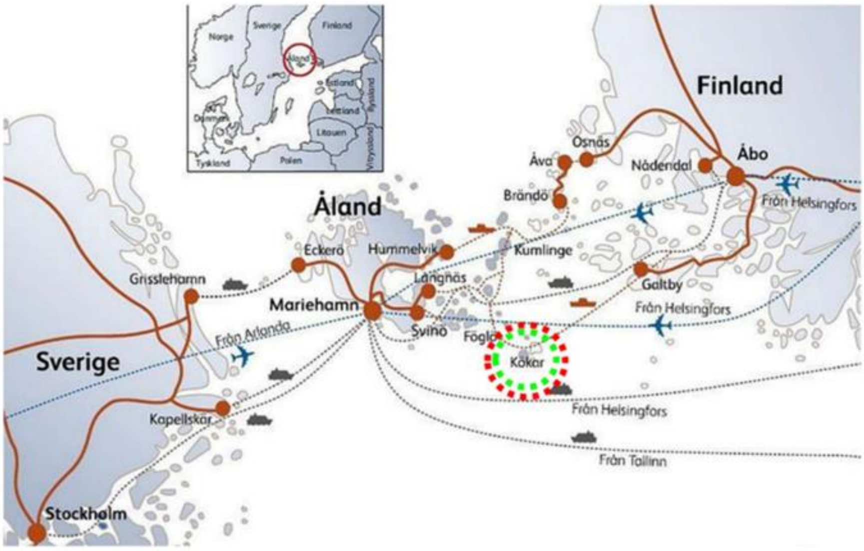

Figure 4: Illustration of the Åland Islands' location with Kökar marked

The population of Kökar island is estimated in about 224 people and 130 households in 2021 (Municipality of Kökar, 2022). Its population varies within seasons, between 160-170 persons living in wintertime, and almost 1,000 in summertime. Furthermore, the island is visited by around 18,000 tourists per year. This situation results in high volatility and puts extra demand on the flexibility of the infrastructure. Consequently, the demand is highly volatile, what leads to extra flexibility requirements of the infrastructures of the place. On winter days, 170 people use the island's system, while in July this turns into a couple of thousands of users. Kökar is connected to the mainland by electric with a transmission capacity of 1.5 MW (Kökar-Sottunga-Gustavs). There is a weak grid connection with occasional outages (3-4 interruptions per year) in the distribution grid that causes local energy problems on Kökar (Vainio, 2020).

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Kökar is a municipality committed to the energy transition agenda, being a pioneering island of the Clean Energy for EU Islands (CE4EUI) Secretariat with a clear sustainability plan within the framework Coast4Us (Vainio, 2020). Within the EU initiative CE4EUI, it was selected as one of 20 Islands in Europe to receive support in its transition process of reducing their CO_2 emissions.

3.2. Current energy characterization of the pilot – Base Year 2017

3.2.1. Annual energy assessment demand

Figure 5 shows the energy consumption by fuel and sector in the island of Kökar, which is estimated around 15,879 MWh (without electricity distribution losses). This information is based on the most updated data that from the Clean Energy Transition agenda (Vainio, 2020) and discussions with local stakeholder.

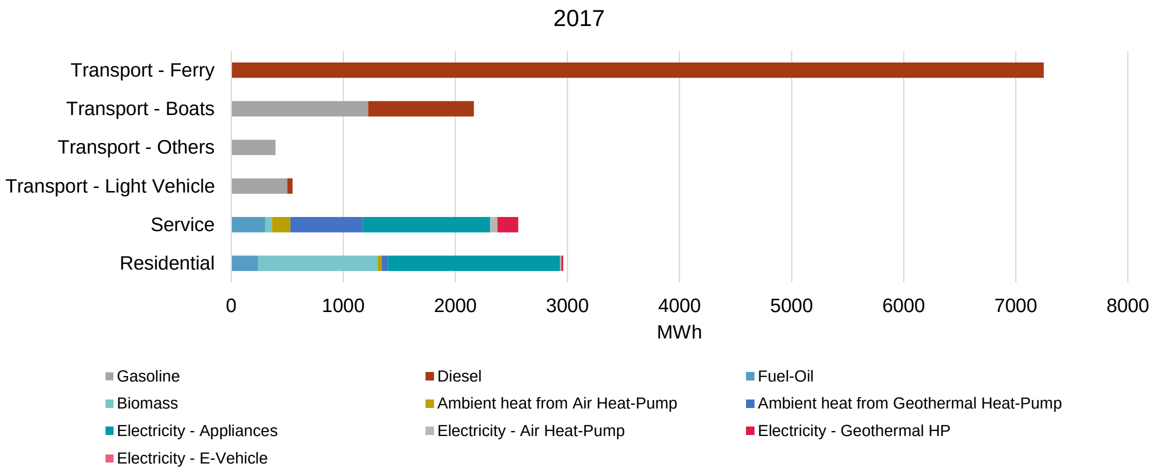

Figure 5: Estimated final energy demand by fuel and sector in 2017 in the island of Kökar

The transport sector is the largest energy consumer sector, and it is split in four subsectors: light vehicles, that encompass all type of cars, boats use mainly for recreative purpose, the ferry that connects Kökar with the mainland, and other transport modes not included in the previous categories, such as truck or motorbikes. Transport sector has an annual energy consumption of 10,353 MWh which represents 65% of the total energy consumption in the island of Kökar. The main consumer is the ferry with around 7,250 MWh, followed by boats with around 2,165 MWh. Both transport modes represent together 91% of the fuel demand in this sector. **Residential sector is the second largest sector** with the higher annual energy consumption with 2,962 MWh. In this sector, **space heating and domestic hot water are the main uses being electricity and biomass the dominant fuels**, covering 53% and 35% of its total fuel consumption. Finally, energy consumption in service sector is mainly divided by tourist services and municipal facilities, which include hotels, restaurants, schools, water treatment, and others. The overall annual energy consumption is 2,561 MWh and it is driven mainly by electricity which covers 56% of its total fuel needs.

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CO_2 EMISSIONS

Figure 6 shows the direct and indirect CO_2 emission by sector for the base year in the island of Kökar. The total CO_2 emissions accounts for 2,989[1] tons of CO_2 of which 95 tons of CO_2 are indirect emissions due to the electricity consumption from the national grid. In the calculation of the indirect CO_2 emissions an emission intensity of electricity production of 68 tons of CO_2 by MWh is considered (CETA, 2020). The transport sector constitutes the main emission source due to the ferry and boats, representing 92% of the overall CO_2 emissions. For the non-transport sector corresponds a minor part, with 144 tons of CO_2 of direct emissions.

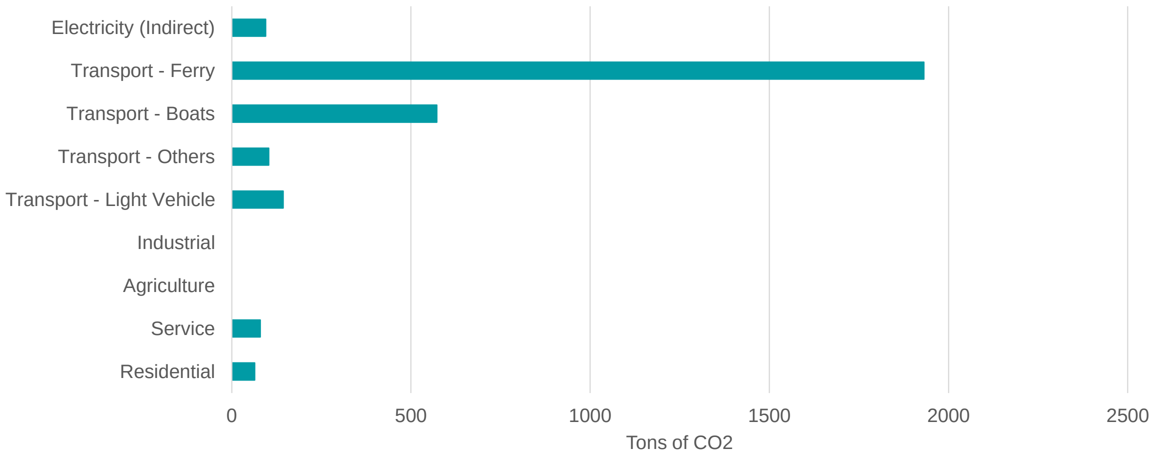

Figure 6: CO_2 emissions by sector of the base year in the island of Kökar

ELECTRICITY DEMAND PROFILE

Figure 7 presents the estimated hourly electricity demand profile in the island of Kökar. The annual total electricity consumption was 2.95 GWh in 2017, year in which the residential and service sectors were responsible for 53 % and 47 % of the total electricity consumption. In both sectors, most of the electricity is consumed by buildings for heating purposes.

HEAT DEMAND PROFILE

The estimated hourly heat demand by square metre profile of the island of Kökar is shown in Figure 8, which is based on the energy use. As there is no information about the hourly load heat demand profile of the island of Kökar, an hourly heat demand profile was created as a combination of two single profiles: one that represents space heating (SH) and another one that represents domestic hot water (DHW). **The profile for space heating considers that heating needs follow the outside temperature in relation to the balance point temperature**. The balance point temperature in all buildings is 17°C, which is the same balance point temperature used, for example, by the Swedish Meteorological and Hydrological Institute (Lind and Nordlund, 2021). **The**

[1] There is a slight difference with (CETA, 2020) due to rounding the calculation numbers.

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DHW profile is a constant value that considers a fix energy consumption for warm water in buildings. Finally, **both profiles are normalized, weighted, and summed up** to estimate the overall hourly heat demand profile. Weights are the average heat consumption by square metre by end in buildings which are estimated for space heating and DHW in 137 kWh/m² and 20 kWh/m², respectively (Lind and Nordlund, 2021).

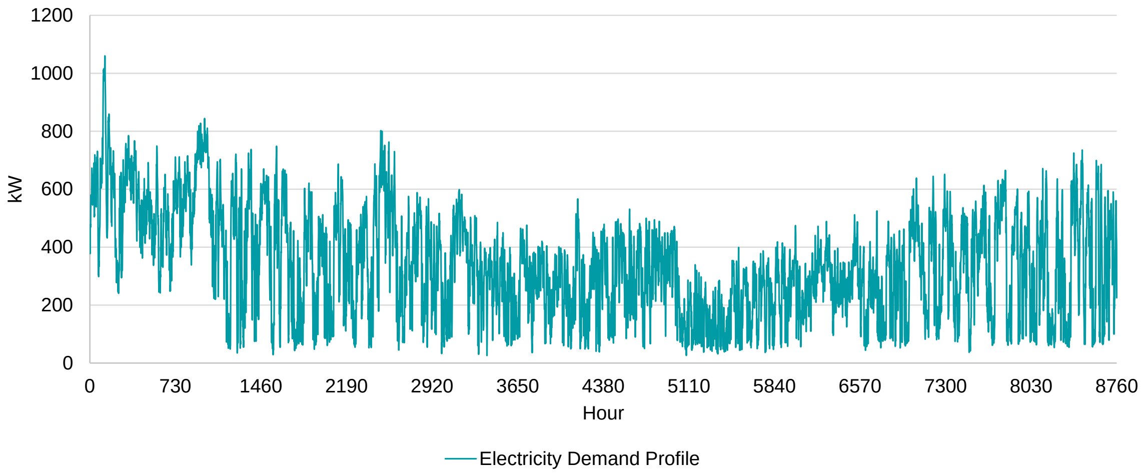

Figure 7: Electricity demand profile for the island of Kökar

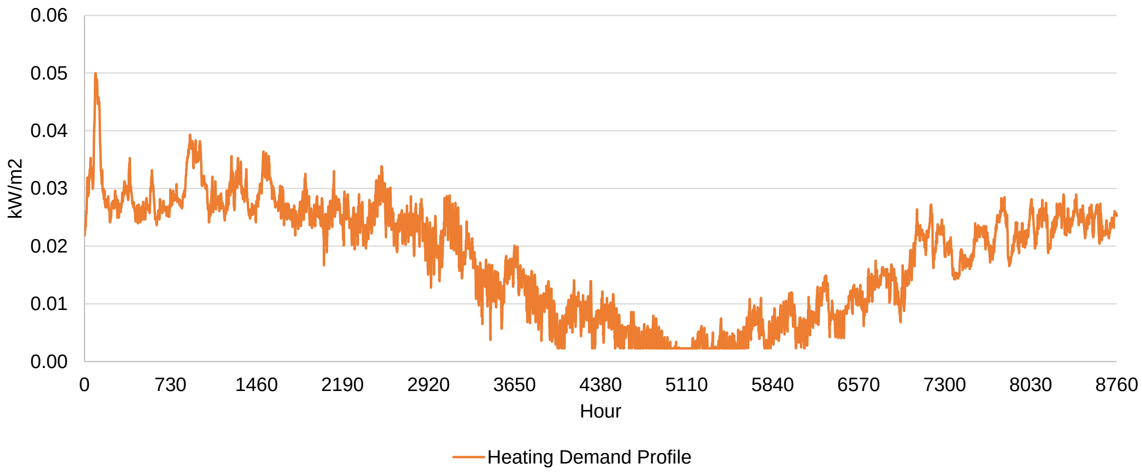

Figure 8: Heat demand profile for the island of Kökar

REFUELLING PROFILE OF THE HYDROGEN-POWERED FERRY

Travelling by ferry is the main transport mode to move from the island to the mainland, the distance of which is about 50 km. Three different ferries are operating in Kökar: Gudingen, Skiftet, and Knipan. The diesel-powered ferry has an annual energy consumption of 7,250 MWh, which represents around 46 % of the total energy needs in the island. The island of Kökar is exploring the possibility to replace the current ferry by a new one powered by hydrogen with fuel cells. The

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electrolyser to generate the hydrogen to refuel the ferry could be expected to be located on the island. In this context, Figure 9 shows daily hydrogen demand profile of the ferry in 2030. This profile was deployed based on the daily schedule of the ferry from Långnäs to Kökar (Aland Travel, 2022), considering that the ferry must be refuelled each time that arrives to the island of Kökar.

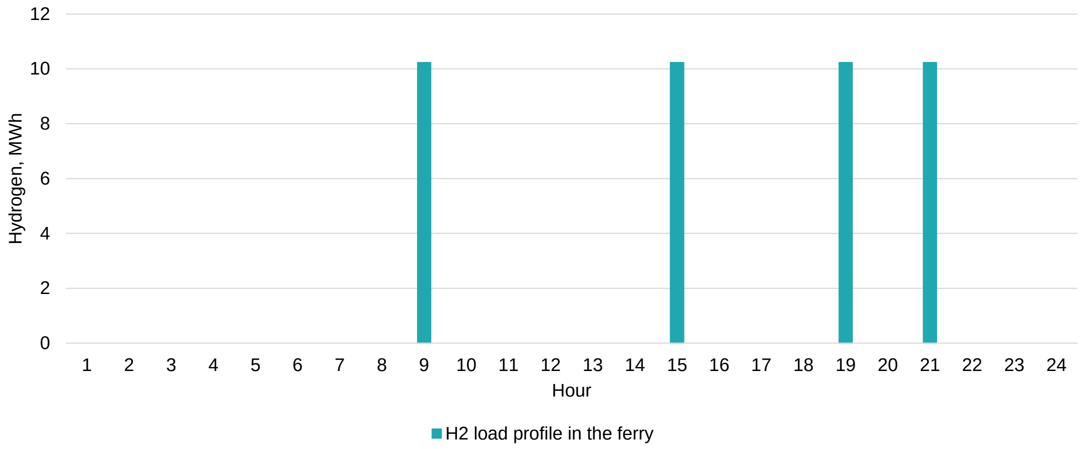

Figure 9: Daily hydrogen demand profile of the ferry in the island of Kökar in 2030

REFUELLING PROFILE OF E-BOATS

It is estimated that **there are around 300 boats in Kökar** based on the number of cottages and citizens (Vainio, 2020). Boats represents an energy consumption of 2,165 MWh (Vainio, 2020). In 2030, island of Kökar expects that **part of the boat fleet will become e-boats**. Figure 10 shows the designed daily electric charging profile for the e-boats in the island of Kökar (Xinman et al., 2021). It is considered that charging time takes place during the night (from 0 a.m. to 8 a.m.) to allow that the e-boat is available for the user during the day (Xinman et al., 2021). In addition, the e-boats are considered to be used only during the summertime (from June to August).

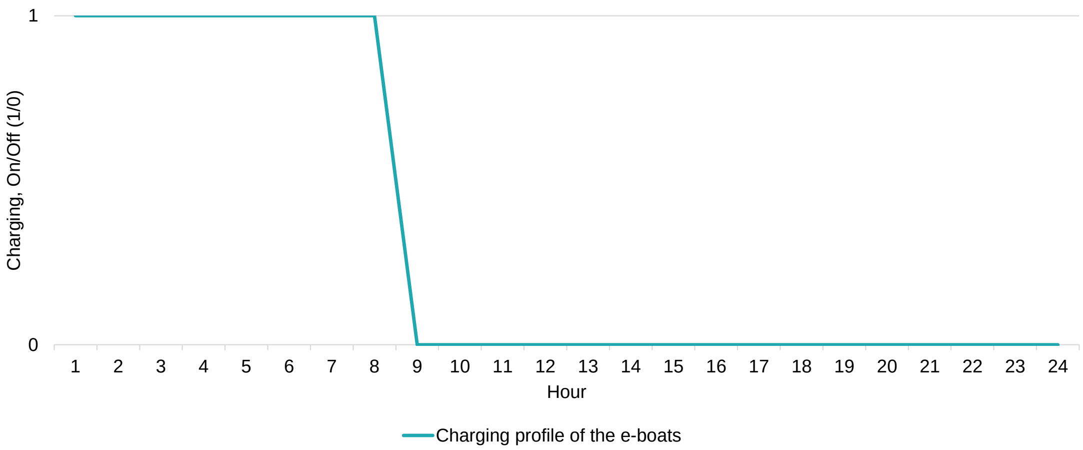

Figure 10: Designed daily electric charging profile for the e-boats in Kökar (Xinman et al., 2021)

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OTHER ASSUMPTIONS CONCERNING THE TRANSPORT SECTOR

Currently, the island of Kökar accounts with one EV, with **transport sector being dominated by gasoline and diesel vehicles**, namely 144 and 16 vehicles in 2017, respectively. This information, together with the fuel consumption, allows to estimate that the island of Kökar has an annual passenger-kilometre[2], of 7,694 pkm and annual vehicle-kilometre[3] around 6,412 vkm with an average of 1.2 passenger per vehicle (Surecity Project, 2019).

3.2.2. Local heat and electricity production capacity

Figure 11 shows the estimated local heat and electricity production, as well as the capacity of the electricity transmission line of the island of Kökar in 2017. **Wind plays the main role in the local electricity production** system through the Mika wind power plant, with an installed capacity of 500 kW. This plant has an annual production of around 1,163 MWh, representing roughly 37% of the annual electricity consumption of the island (Vainio, 2020). There are also several micro-turbines with a total capacity of 30 kW, producing around 65 MWh/year (Vainio, 2020). Complementing the wind power, the island has **PV roof systems with a total power capacity of 49 kWp** and an estimated production of 44 MWh/year (Vainio, 2020). In the heating sector, **biomass heater is the most relevant technology** with and estimated capacity of around 360 kW that produces around 949 MWh_{th}. HPs (ground- and air-source) are also relevant, with an estimated total capacity of 380 kW_{th}. Finally, as previously said, the island is **connected to the mainland by an electric underwater cable with a capacity of 1.5 MW** (Kökar-Sottunga-Gustavs). In the distribution grid there is a weak connection, with occasional outages (3-4 interruptions per year) (Vainio, 2020).

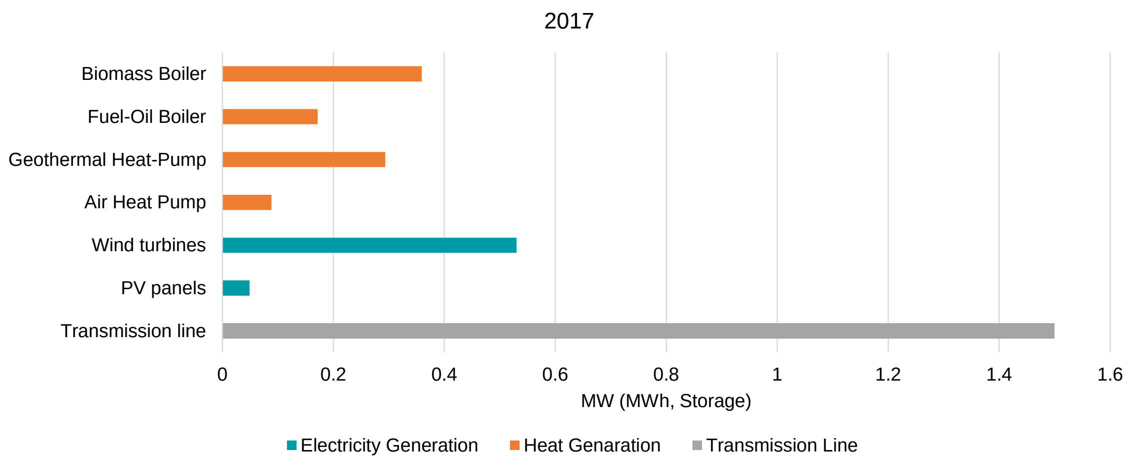

Figure 11: Local heat and electricity production capacity and electricity transmission line capacity in Kökar

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[2] pkm: Unit of measurement representing the transport of one passenger by a defined mode of transport (road, rail, air, sea, inland waterways etc.) over one kilometre (Eurostat - European Commission, 2022).
[3] vkm: Unit of measurement representing the movement of a vehicle over one kilometre. The distance to be considered is the distance actually run. It includes movements of empty vehicles. Units made up of a tractor and a semi-trailer or a lorry and a trailer are counted as one vehicle (EEA, 2022).

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ELECTRICITY PRICES PROFILE

The only transmission system operator (TSO) of the island is Kraftnät Åland (KNÅ). KNÅ has the obligation to both ensure power supply for the inhabitants of the Islands and the stability in the whole system from the inside and outside, as the local TSO connecting Åland with the Swedish synchronized grid. This makes that **electricity prices in the island of Kökar depend on Swedish bidding zone SE3**. Electricity prices profile for Sweden in 2030 is presented in Figure 12. It is expected that Swedish electricity prices will have a high fluctuation due to increase of vRES connected to the national grid being average prices around 30.8 €/MWh in 2030. In this context, Swedish electricity prices, as well that the transmission line capacity which connects the island of Kökar to the mainland Åland, determine how the energy community interact with its national market defining how trading (import/export electricity) take places under a least-cost solution framework.

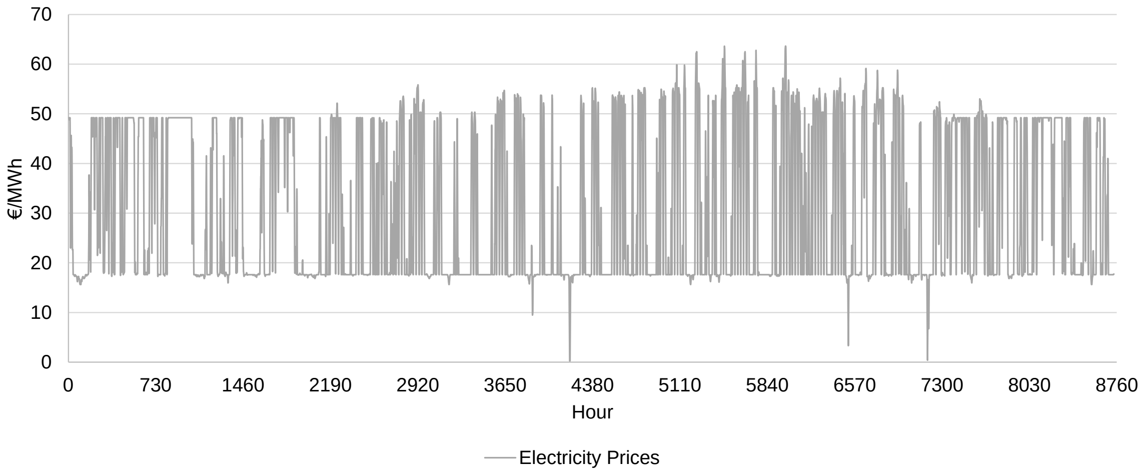

Figure 12: Electricity prices profile for Sweden in 2030

SOLAR PROFILE

Figure 13 shows the hourly electricity production profile for PV panels in the island of Kökar. This profile was built using the PVGIS tool (JRC-European Commission, 2022) taking as reference a crystalline silicon PV panel with a nominal power of 1 kWp and solar data from 2016. This PV profile is also used to define thermal energy production from solar thermal panels.

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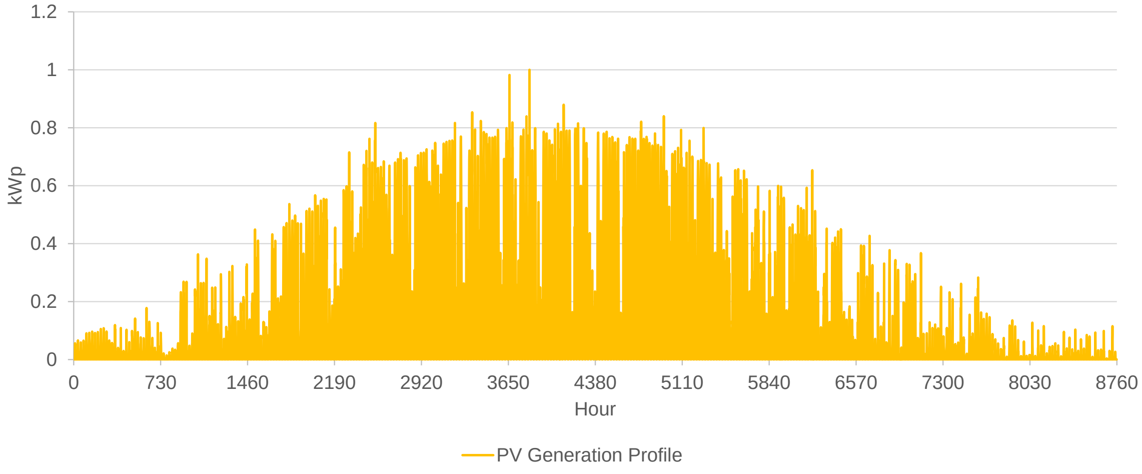

Figure 13: Electricity production profile for PV panels in island of Kökar (normalized to 1 kWp)

WIND PROFILE

Figure 14 shows the hourly electricity production profile for wind turbines in the island of Kökar. This profile is based on measured data in the Mika wind power plant in 2019. This is because Mika wind plants was under refurbishment in 2017 and no electricity production took place during that year. Therefore, it is assumed that electricity production profile is equivalent for both years.

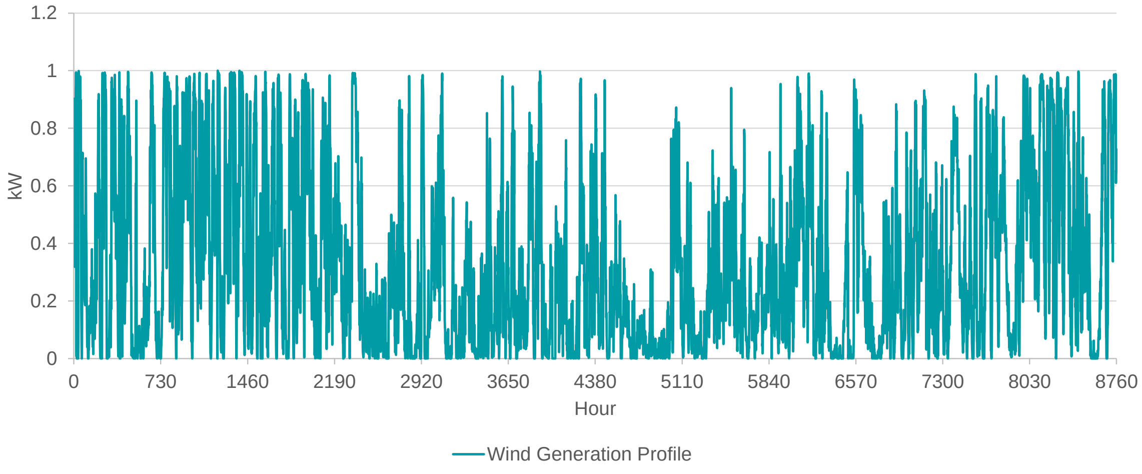

Figure 14: Electricity production profile for wind turbine in island of Kökar (normalized to 1 kW)

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3.3. Scenario definition

Three scenarios are explored within the LocalRES project for the island of Kökar. The goal of these scenarios is to define the least-cost solutions for different possibilities on the long-term perspective (2030) about how the establishment of a hypothetical energy community including all the village can support and perform the energy decarbonization of the island. In this analysis, the impact of flexible measures such as demand side management (DSM), smart charging for EVs, energy storage, HPs as well as the use of PV panels, wind turbines and hydrogen production is explored in these scenarios. These scenarios were developed together with local stakeholders.

- ***Reference Scenario (Ref-SC):*** In this scenario the island concentrates their efforts in **replacing the fossil fuel heating systems by HPs and promoting the use of electrical vehicles and electrical boats**. This scenario also includes the **increase of vRES** capacities (mainly PV and wind) based on NECP (European Commission, 2022) as well as **flexibility measures** (smart charging for EVs, DSM and energy storage such as batteries and thermal energy storage).
- ***Energy Balance Scenario (EB-SC):*** In this scenario, the island keeps their effort in replacing the fossil fuel heating systems by HPs and promoting the use of electrical vehicles and electrical boats as well as the flexibility measures in the same way as in the Ref-SC. In addition, it is explored **an increase of vRES capacities to achieve electricity balance** (local electricity production equals to electricity demand) and **double the capacity of the transmission line** connected to the island.
- ***Transport Decarbonization Scenario (TD-SC):*** This scenario considers all the main aspect included in EB-SC, but it goes a step further to decarbonize the transport sector. In this sense, **hydrogen-powered ferry will replace the current ferries** driven by fossil fuel, **all the cars by e-vehicles and half of the boats by e-boats**. The necessary **additional infrastructure to generate the hydrogen and additional electric capacity** are also considered. Moreover, this new infrastructure must be in the island.

Table 3 summarizes the technical description for the island of Kökar's scenarios. In the Ref-SC and the EB-SC the replacement of the fossil fuel-based boilers as well as the transport sector are equivalent, while in the transport sector it is considered that 10% of vehicles and 10% of the boats will be electrified by 2030. The main difference for both scenarios is the EB-SC´s goal to achieve the energy balance in terms of electricity in the island. The expected increase of vRES capacities (mainly PV and wind) implies to double the capacity of transmission line that connects the island to the national grid moving from 1.5 MW to 3 MW to facilitate the electric trading and remove bottle necks. **TD-SC is the most ambitious scenario**, with the electrification of the 100% of the vehicles and 50% of the boats, the use of hydrogen-powered ferry to connect the island with the mainland as well as all the necessary capacity such as the electrolyser and additional vRES. In this last scenario, the 3 MW capacity of transmission line are kept because the dependence with the national grid is the most critical.

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Table 3: Scenario characteristics in the island of Kökar in 2030

	Ref-SC	EB-SC	TD-SC
Allowed PV	Following NECP	Up to obtain Energy Balance	Up to obtain Energy Balance
Allowed wind	Following NECP	Up to obtain Energy Balance	Up to obtain Energy Balance
Max. allowed electric batteries	No restrictions	No restrictions	No restrictions
Heat pumps	Replace 100% of fossil fuel heating boilers	Replace 100% of fossil fuel heating boilers	Replace 100% of fossil fuel heating boilers
DSM	Available	Available	Available
E-vehicles	10% of vehicles	10% of vehicles	100% of vehicles
Type of e-charge	Smart charging	Smart charging	Smart charging
E-boats	10% of boats	10% of boats	50% of boats
H_2-powered ferry	N/A	N/A	Available
Transmission capacity to national grid	1.5 MW	3 MW	3 MW

3.4. Energy demand projection for the scenarios

Several drivers and assumptions are required to establish and estimate the forecasted energy demand of the island of Kökar by 2030.

The residential sector is the second largest energy consumer sector. **The drivers to estimate the future DHW and electricity demand are based on population forecasting, while space heating demand is linked to the refurbishment rate of buildings**. It is expected that the population in the island of Kökar will remain the same, causing the energy consumption for DHW to be the same. Despite the number of buildings remain the same in 2030, the impact of the refurbishment in buildings will reduce the heat demand for space heating. It is assumed an annual refurbishment rate of 0.7%, which means around 8.3% reduction of the current heat demand in 2030.

The population forecasting is the main driver for service and transport sectors. As the population will remain stable in the island, the current services are expected to be able to cover future needs of the inhabitants, and the number of cars and boats will remain the same. This causes their future energy demand remaining the same as the current one. Finally, no changes in the number of connections by ferry to the main island are assumed.

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Accordingly, **two future energy demand scenarios** named DMD-Ref and DMD-TD for the different energy sectors are estimated in 2030. These scenarios are built by combining different drivers to estimate future demand by sectors in the island of Kökar. Furthermore, they consider scenario specifications as well as the impact of shifting to more efficient technologies.

Figure 15 shows the DMD-Ref demand scenario, which is applied in case of the Ref-SC and the EB-SCs to capture the 10% of EVs penetration and boats as well as the fully replacement of fossil fuel boilers by electric HPs.

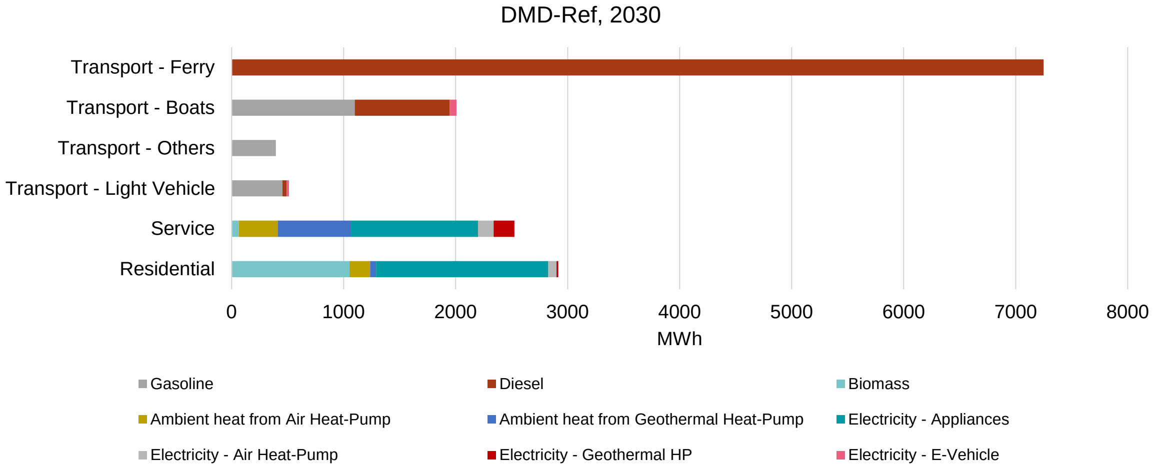

Figure 15: DMD-Ref demand scenario in the island of Kökar in 2030

In this demand scenario, **fossil fuel has a major role due the diesel dependence of maritime transport sector**. DMD-Ref considers an overall fuel demand of 15,604 MWh in 2030 (without electricity distribution losses) that represent around 2% less of the energy consumption compared to 2017. This is due to the building refurbishment process in residential buildings as well as the use of more efficient technologies. Due to electrification of heating and transport sectors, electricity demand grows up to 3,171 MWh, 7% more compared to 2017, representing 20% of the total energy demand.

The residential sector remains as the second largest energy sector with a total fuel consumption of 2,914 MWh, representing a slight reduction of around 2% compared to 2017. Electricity is the main energy source with 1,626 MWh of fuel consumption followed by biomass with 1,051 MWh. **Due to the replacement of the fossil fuel boilers, there is a high increase on the use of air-source HPs** generating 258 MWh of heat, of which 74 MWh is accounted for electricity while the remaining energy comes from heat extraction from the ambient air.

The service sector accounts for 2,525 MWh of fuel consumption in 2030, that represents around 1% reduction compared to 2017. In the same way as residential sector, the use of air-source HPs has a high increase generating 492 MWh, of which 140 MWh is accounted for electricity.

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The transport sector is the largest energy intensive sector with a total fuel consumption of 10,165 MWh, representing a slight reduction of around 2% compared to 2017. The is because **EVs and e-boats engines have a higher efficiency compared to internal-combustion engine (ICE)** used commonly. **Diesel-powered ferries are main fuel consumers** with 7,250 MWh representing 46% of the fuel needs of the island.

Figure 16 represents the DMD-TD scenario. This scenario refers to the energy projections for the TD-SC in which hydrogen-powered ferry is established as well as the fully electrification of the light vehicles and half of the boats.

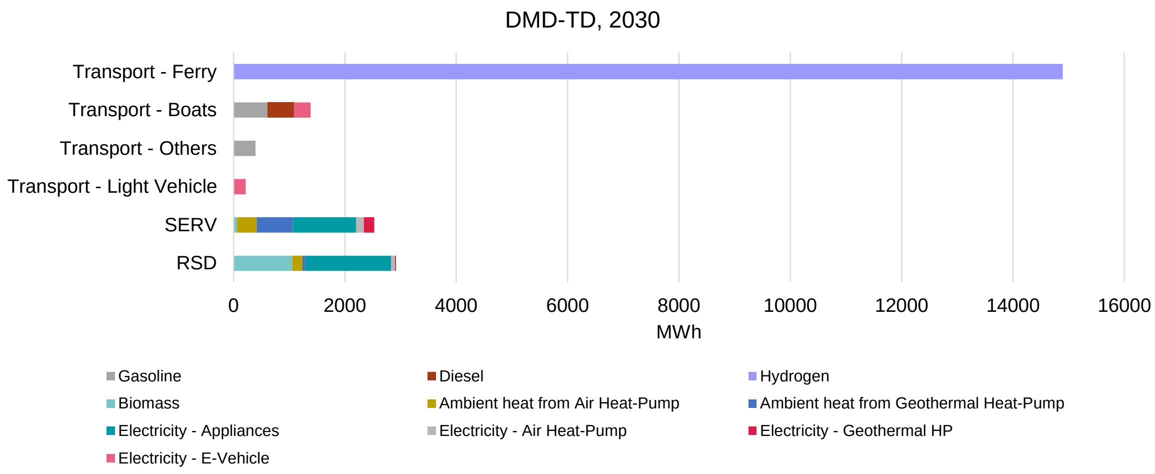

Figure 16: DMD-TD demand scenario in the island of Kökar in 2030

DMD-TD scenario implies an overall fuel demand of 22,333 MWh (without electricity distribution losses), which represents 41% more of the overall fuel demand in 2017. This is mainly due to the replacement of the diesel-powered ferry by another one driven by hydrogen. It is estimated that hydrogen turbine of the ferry has an efficiency of 0.6 (60%) and needs to generate annually 8,857 MWh of useful energy. This implies a yearly energy consumption of 14,895 MWh of hydrogen (443 tons of hydrogen) that must be generated by an electrolyser located in the island of Kökar.

In 2030, it is expected that 100% the light vehicles circulating in the island are e-vehicles and the 50% of boats are e-boats. These subsectors consume 520 MWh of electricity in which 219 MWh will be e-vehicles and the remaining part e-boats. This implies an overall reduction of their fuel needs of 60% and 36% compared to 2017, respectively.

Finally, in this scenario, **there are not fundamental changes in residential, service, and other transports sectors**. Therefore, their fuel demand by technology remains the same as in DMD-Ref.

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3.5. Results and Discussion

In this section the simulation results of the Ref-SC, EB-SC and TD-SCs are presented. The results address how electricity and heating sectors in the island of Kökar are covered by local energy resources and production technologies, as well as by different flexibility measures such as power exchange (imports/exports) or DSM.

3.5.1. Ref-SC

Figure 17 shows the overall local heating and electricity production and transmission line capacity in the island of Kökar for the Ref-SC. In this scenario, new capacities PV and wind developments follow the Finnish NECP in combination with local constrains. In this sense, **an increase of 50% of the installed capacity for both technologies is estimated**. This allows to achieve an overall installed PV capacity of 74 kWp and wind production capacity of 795 kW in 2030. **Electric batteries are not required due the high capacity of the transmission line** that allows to trade with the mainland to balance the electric system and avoid bottlenecks. In the heating sector, **there is a general reduction of the installed heating capacity** compared to 2017 because of the decrease of heat demand as well as the replacement of fossil boilers by air-source HPs. Biomass boiler is the main technology with 355 kW followed by ground-source HP with an installed heat capacity of around 300 kW. Air-source HP is the third heating technology; however, the installed heat capacity grows up to around 250 kW, almost threefold more compared to 2017.

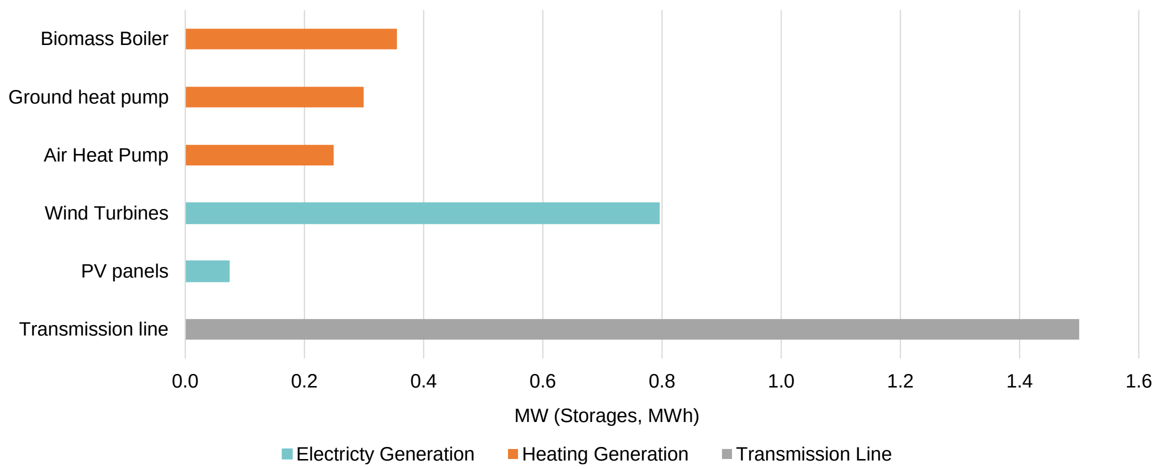

Figure 17: Installed local heat and electricity production capacities by technology and electricity transmission line capacity according to the Ref-SC in the island of Kökar in 2030

ELECTRICITY SECTOR

Figure 18 shows the annual electricity demand in Ref-SC by different consumption technologies as well as the impact of DSM per week in the island of Kökar in 2030. Total electricity demand is estimated as 3,272 MWh (including 3% of electricity distribution losses) in annual bases. **Electric appliances are the main electricity consumers** with 2,770 MWh, responsible for 85 % of the total

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electricity demand. Electricity consumption for space heating (air-source HPs and geothermal HPs) accounts for 362 MWh of electricity, mainly concentrating this demand during wintertime. **DSM[4] has a small contribution**, shifting around 16 MWh of the electric demand for heating from HPs. Finally, **electricity demand of the e-boats is concentrated in the summertime** and can represent up to 16% of the overall weekly electricity demand during summertime.

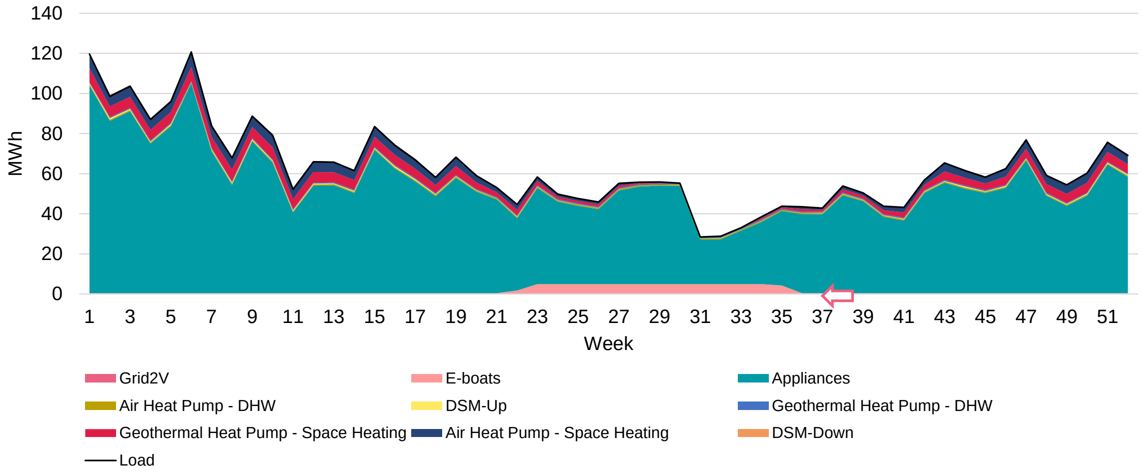

Figure 18: Annual electric demand by technology according to the Ref-SC in Kökar in 2030

Figure 19 and Figure 20 illustrate hourly electricity demand profiles for the island of Kökar for the first two weeks of January and July in 2030, illustrating winter and summer periods, respectively. Figure 19 shows that **DSM and charging of e-vehicles has low impact on the modification of the overall electricity demand profile**. This is because the capacity of HPs, as well as the number of EVs, is relatively low compared to other electrical devices. Both figures show that the charging of EVs produces a small saw-tooth consumption profile because charging batteries are concentrated in the moment of the day with the lowest electricity price. Figure 20 reflect that **the use of e-boats during the summertime has a large impact on the electricity demand profile** representing in average to 30% of the hourly electricity demand during the charging of batteries in this period.

[4] DSM-Up: Electricity overconsumed to "overheat" the building. DSM-Down: Electricity saved due to reduction of heating in the building by DSM.

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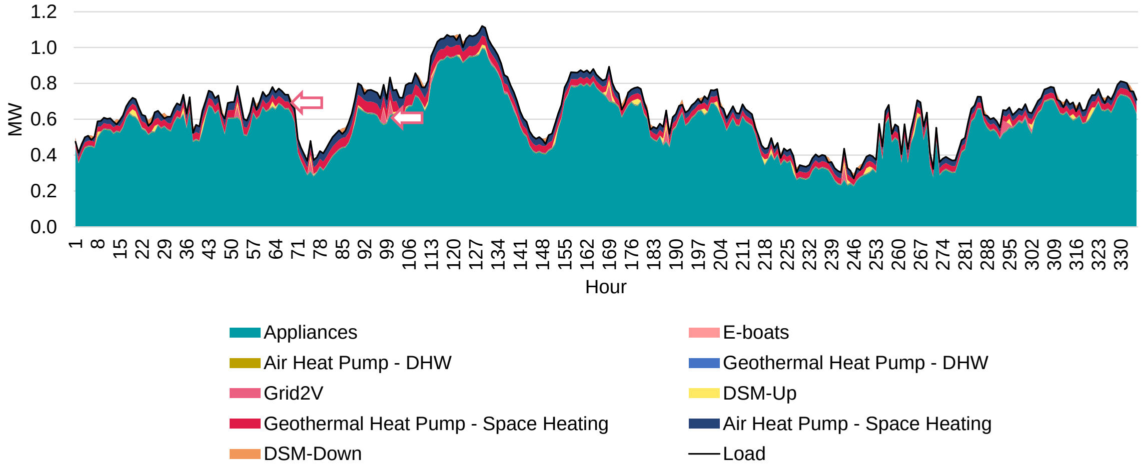

Figure 19: Hourly electricity demand in the first two weeks of January according to the Ref-SC in the island of Kökar in 2030

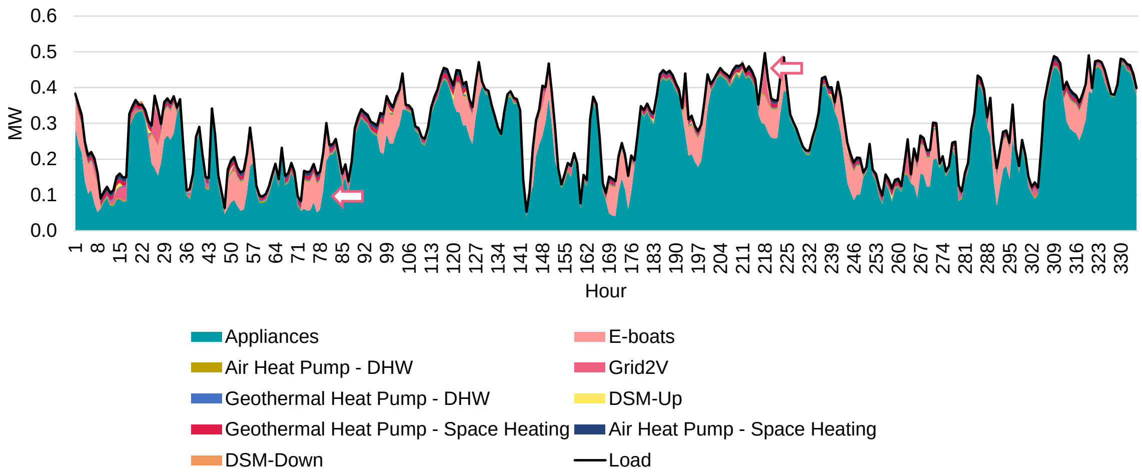

Figure 20: Hourly electricity demand in the first two weeks of July according to the Ref-SC in the island of Kökar in 2030

Figure 21 shows the annual electricity supply per week in Ref-SC from local sources, imports and exports in 2030. **Positive values represent electricity supply from different options to meet the electricity demand, whereas the negative values represent the electricity that is exported**. The annual locally-generated electricity in the island of Kökar is 2,334 MWh; the equivalent to 71% of the total electricity demand (including transmission losses). **Wind electricity production is the main energy source** producing 2,277 MWh of electricity, 98% of the overall local electricity production. Annual electricity imports are 1,559 MWh, and considering that wind is the main local electricity production source, there are fluctuations in the electricity import needs during the year, covering in average 47% of the weekly electricity demand. Finally, electricity exports amount to 621 MWh with the highest weekly export of 41 MWh during the first week of December.

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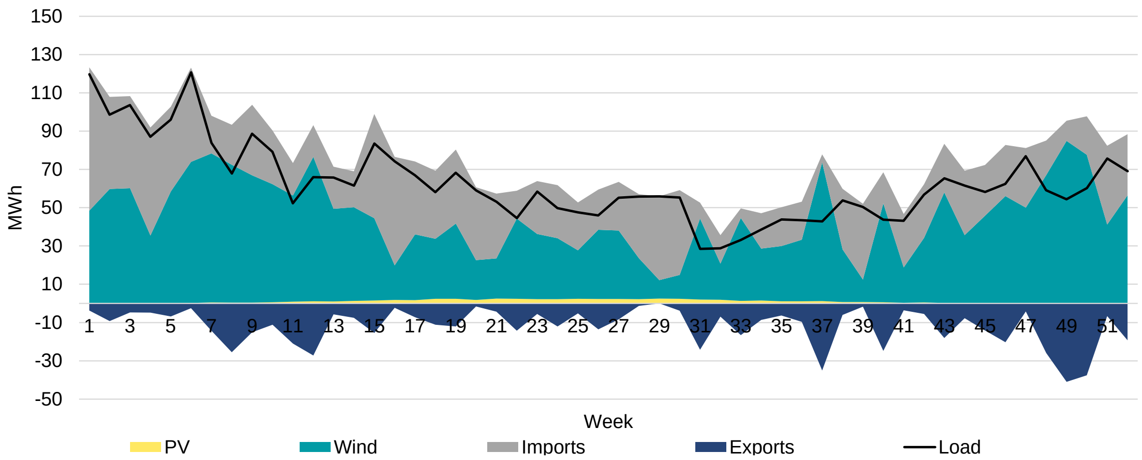

Figure 21: Annual electric supply by technology according to the Ref-SC in Kökar in 2030

Figure 22 and Figure 23 illustrate the hourly electricity supply profile for the island of Kökar for the first two weeks of January and July in 2030, respectively. Both figures show how **the surplus of electricity production mainly from the wind turbines is exported to the national grid**. The current capacity of 1.5 MW of **the transmission line connecting the island with the mainland is enough to absorb all electricity surplus** production as the largest export need capacity of the transmission line is 0,7 MW.

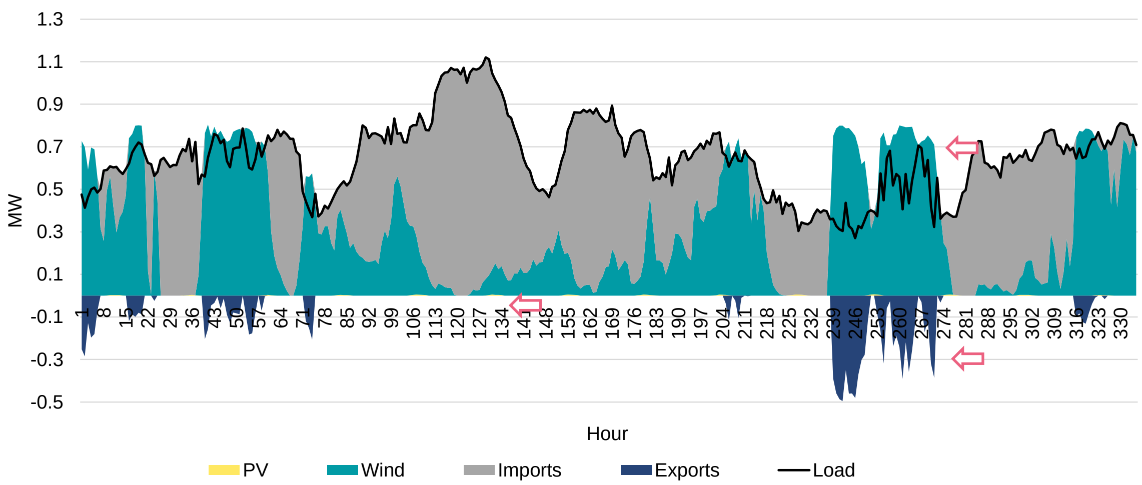

Figure 22: Hourly electricity production in the first two weeks of January according to the Ref-SC in the island of Kökar in 2030

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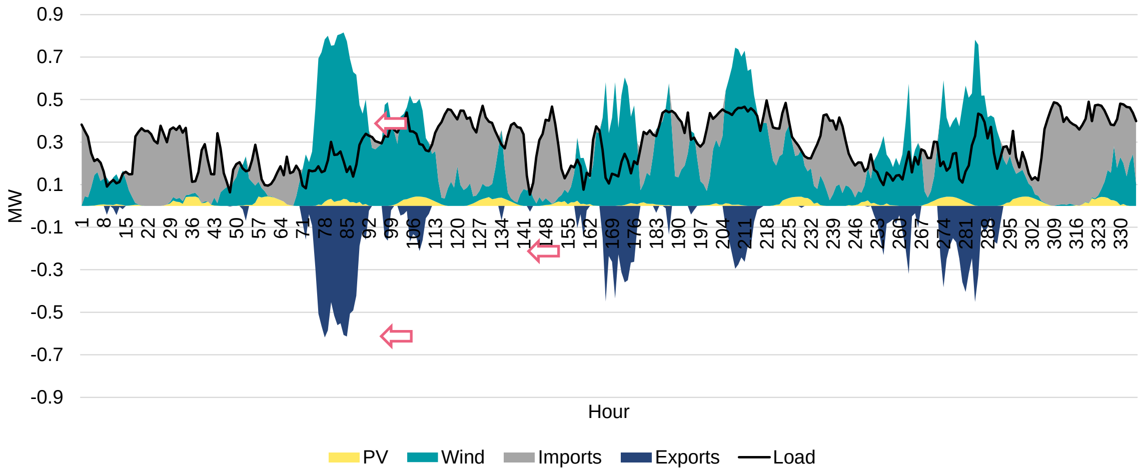

Figure 23: Hourly electricity production in the first two weeks of July according to the Ref-SC in the island of Kökar in 2030

HEATING SECTOR

Figure 24 shows the annual heat supply in Ref-SC per week by different heat production technologies in 2030. In the island of Kökar, **heat is produced and consumed locally, hence heat trading with an external network out of the community is not possible**. The total heat production is estimated in 2,610 MWh (including distribution losses) on an annual basis. **Biomass boilers are the main heat source** with 937 MWh followed by geothermal HPs to cover the space heating and DHW with 913 MWh of heat, which represent 36% and 35% of the total heat supply, respectively. Electricity consumption of geothermal and air-source HPs are similar, however geothermal HPs generate more heat due to the highest COP (coefficient of performance) of these technologies.

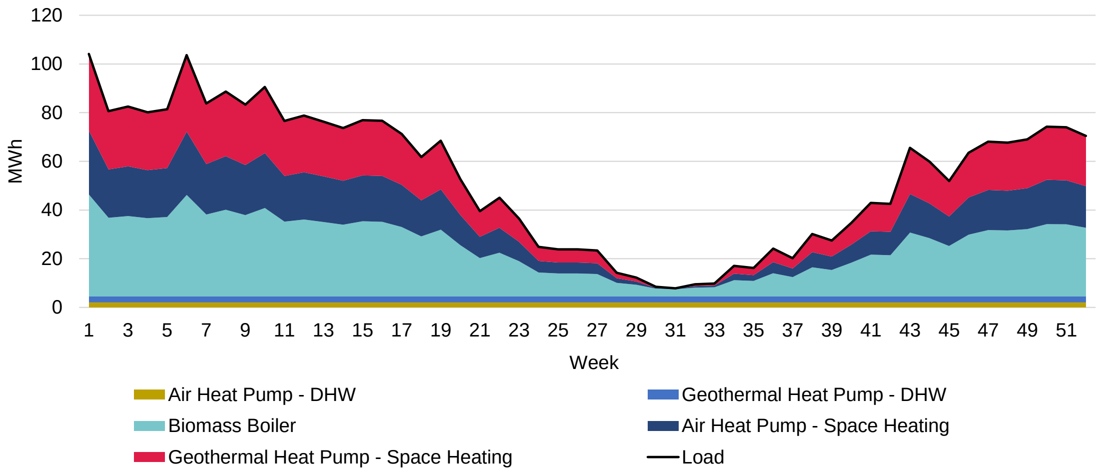

Figure 24: Annual heat production by technologies according to Ref-SC in Kökar in 2030

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Figure 25 and Figure 26 illustrate hourly heat production profiles for the first two weeks of January and July in 2030, respectively. Figure 25 shows a heat production profile which is characterized by a sequence of peaks and valleys. This is because of a high proportion of HPs contributing to cover the space heating thermal demand and the DSM system connected to these technologies. The small fluctuations in the electricity profile generated by the DSM system are amplified to the heat demand profile due to the COP of the HPs. This is especially relevant in geothermal HPs as this technology has a higher COP. This effect is reduced during the summertime because the space heating demand is lower.

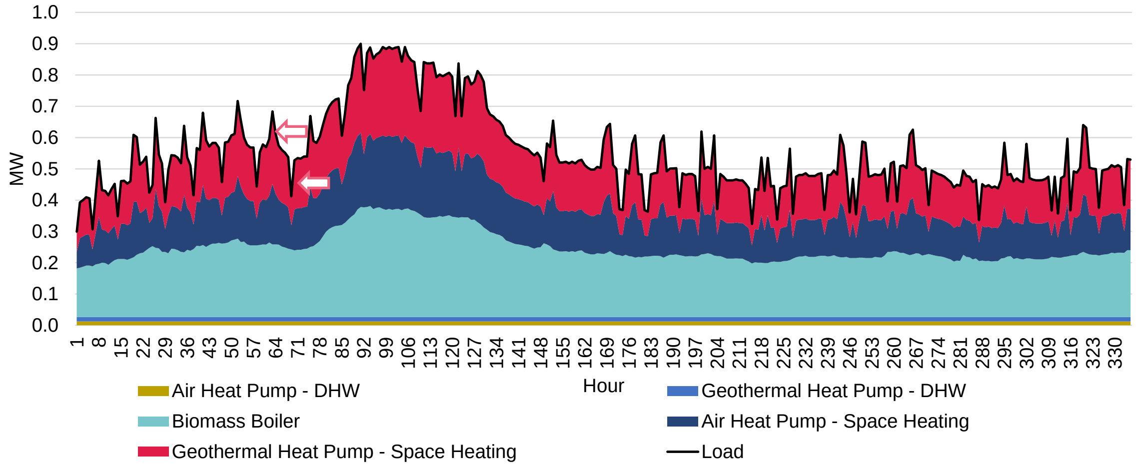

Figure 25: Hourly heat production by technologies in the first two weeks of January according to the Ref-SC in the island of Kökar in 2030

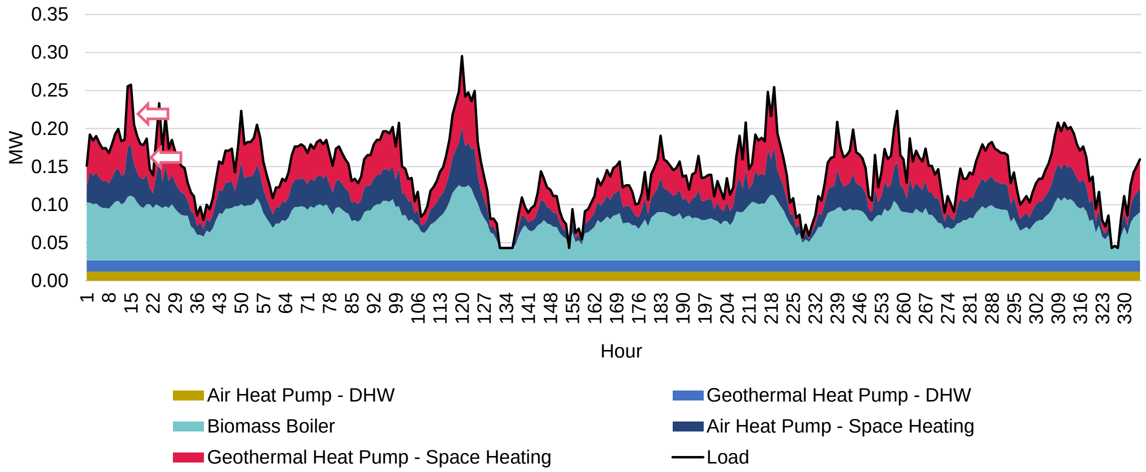

Figure 26: Hourly heat production by technology in the first two weeks of July according to the Ref-SC in the island of Kökar in 2030

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CO_2 EMISSIONS

Figure 27 shows the direct and indirect CO_2 emissions by sector of the Ref-SC scenario in the island of Kökar. The total CO_2 emissions account for 2,743 tons of CO_2, of which 95 tons of CO_2 are indirect emissions due to the electricity consumption from the national grid. For the calculation of the indirect CO_2 emissions in 2030, 68 tons of CO_2 by MWh are considered, the same emission intensity of electricity production of the base year. This is based on the Swedish NECP (European Commission, 2022) together with the low emission intensity of electricity production already considered on the base year (CETA, 2020). In this scenario all the direct emissions of all the sectors are avoided except the ones related to the transport sector. In this sense, there is a reduction of 3% in the overall CO_2 emissions compared with the base year due to the replacement of fossil fuel boilers by HPs and the use of e-boats and e-vehicles. The higher PV and wind local electricity production have a positive impact on the indirect emissions with a reduction of 33% compared to the base year. Nevertheless, the high CO_2 emission from the diesel-powered ferry implies that the CO_2 emission in the island of Kökar are still very high.

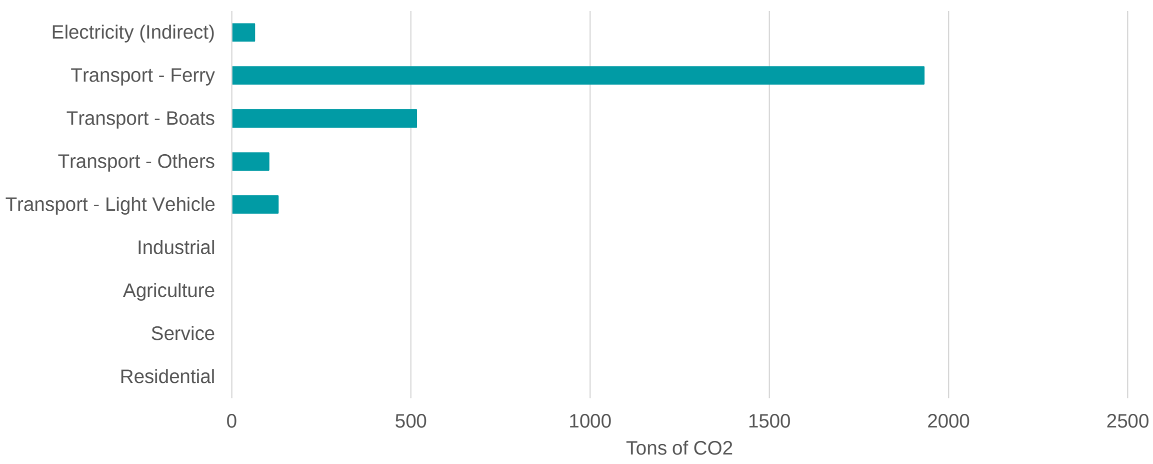

Figure 27: CO_2 emissions by sector of Ref-SC scenario in the island of Kökar

3.5.2. EB-SC

In Figure 28 shows the overall local heating and electricity production and transmission line capacity in the island of Kökar for the EB-SC. This scenario explores the increase of vRES capacities to achieve electricity balance (local production equals to demand) in the island of Kökar. In this scenario, installed PV capacity remains as for Ref-SC, with 74 kWp. However, **wind capacity has a high increase** with an installed capacity of 1,122 kW, 41% more compared to Ref-SC, being the main responsible to achieve the electricity balance. **Electric batteries are not required** due the capacity of the transmission line of 3 MW that allows to trade with the mainland to balance the electric system and avoid bottlenecks. The heating sector performs similarly as for Ref-SC because no additional assumptions are adopted. Therefore, **biomass boiler is the main technology** with 355 kW followed by ground-source HP with an installed heat capacity of around 300 kW and the installed thermal capacity of air-source HPs grows up to around 250 kW.

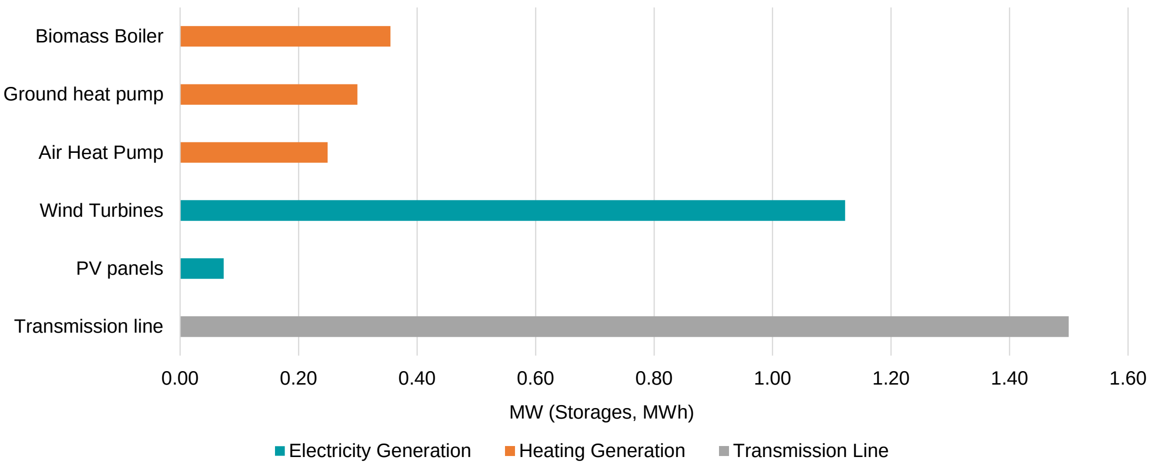

Figure 28: Local energy production capacity and transmission line capacity of the EB-SC in the island of Kökar in 2030

ELECTRICITY SECTOR

Figure 29 shows the annual electricity demand per week in the EB-SC by different consumption technologies as well as the impact of DSM in the island of Kökar in 2030. This electricity load is similar as in the Ref-SC since both scenarios must meet the load projection of the DMD-Ref demand scenario. Therefore, as in the Ref-SC, total electricity demand is estimated as 3,272 MWh (including 3% of electricity distribution losses) in annual bases where electric appliances are the main consumers with 2,770 MWh and electricity consumption for space heating (air-source HPs and geothermal HPs) accounts for 362 MWh of electricity, concentrating this demand during wintertime. **DSM have a higher contribution compared to Ref-SC** shifting around 24 MWh of the electric demand.

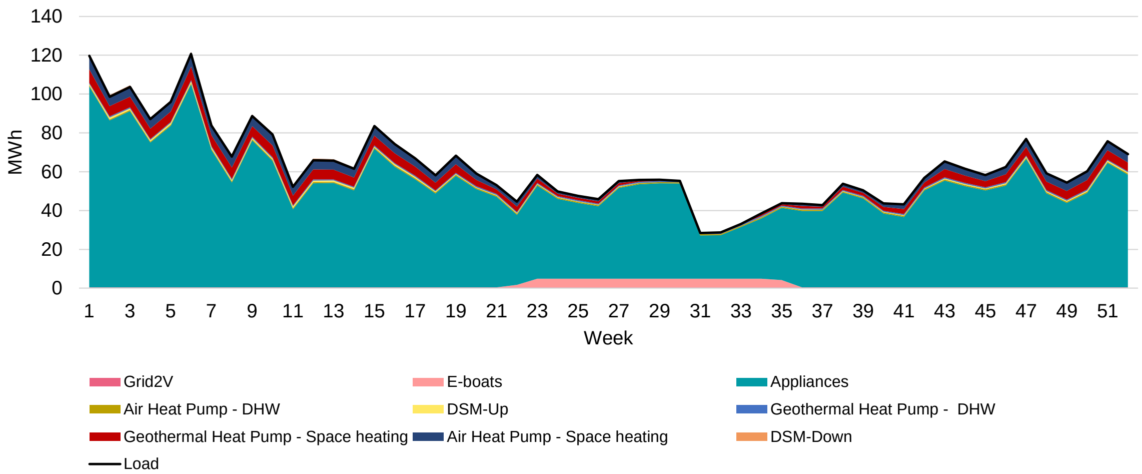

Figure 29: Annual electric demand by technology according to the EB-SC in Kökar in 2030

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Figure 30 and Figure 31 illustrate hourly electricity demand profiles for the island of Kökar for the first two weeks of January and July in 2030, representing winter and summer periods, respectively. There are not fundamental changes compared to the Ref-SC, DSM and charging of EVs have also low impact on the modification of the overall electricity demand profile because the larger weight in the electricity demand of the electrical devices. **E-boats have a high influence in the electricity demand profile during summertime**. As in the Ref-SC, e-boats represent in average around 30% of the hourly electricity demand during the charging of batteries.

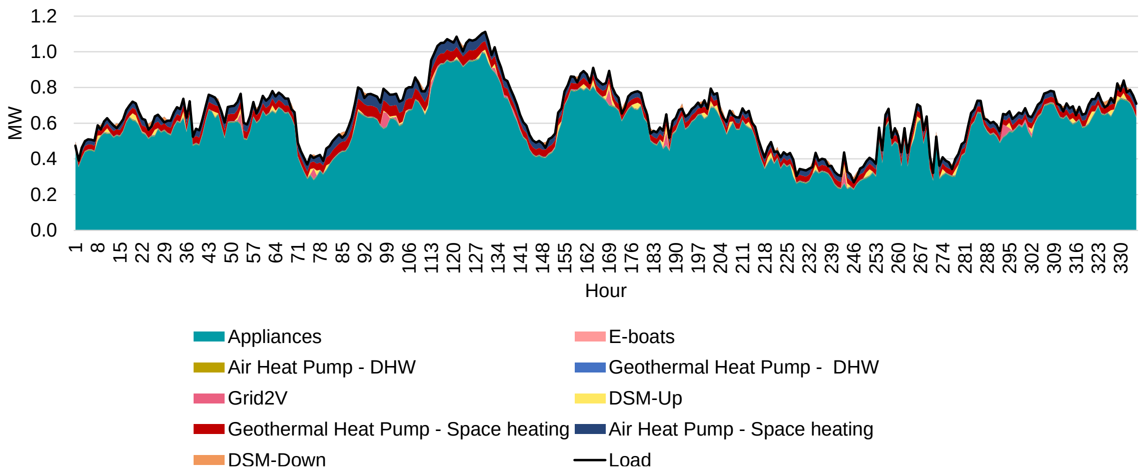

Figure 30: Hourly electricity demand in the first two weeks of January according to the EB-SC in the island of Kökar in 2030

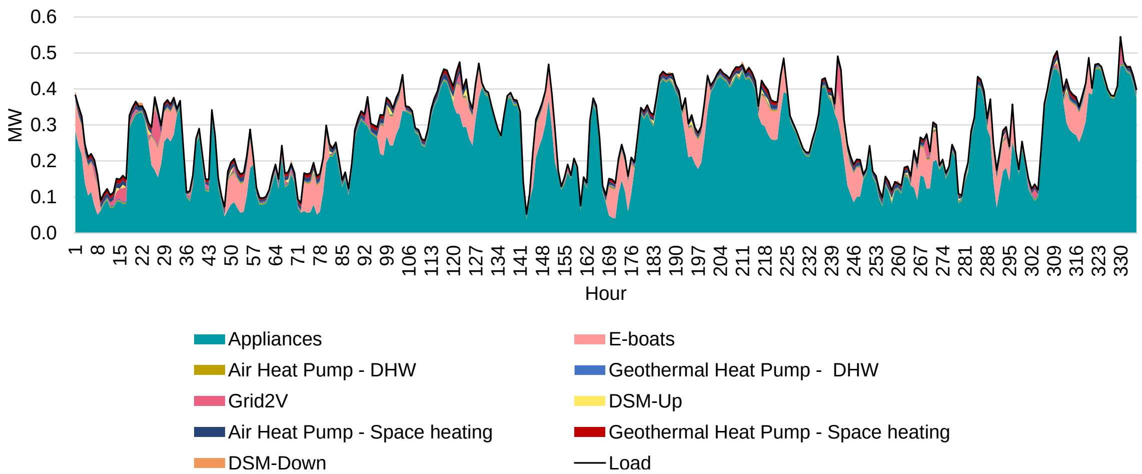

Figure 31: Hourly electricity demand in the first two weeks of July according to the EB-SC in the island of Kökar in 2030

Figure 32 shows the annual electricity supply per week in the EB-SC from local sources, imports and exports in 2030. Positive values represent electricity supply of different options to meet the electricity demand, and negative values the electricity that is exported. **The annual locally-**

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generated electricity in the island of Kökar is 3,272 MWh, the same as the electricity demand (including transmission losses). **Wind electricity production is the main energy source** producing 3,216 MWh of electricity being PV electricity production a minor part, with around 56 MWh. Electricity imports and exports accounts to 1,307 MWh for both. This represents a reduction of 16% in the electricity imports and increase of 110% of electricity export compared to Ref-SC. This is due to a larger local electricity production. The transmission line of 3 MW has enough capacity to allow the electricity trading between the island and the mainland, being the largest importing and exporting capacity in the transmission line 1.08 MW and 0.99 MW, respectively.

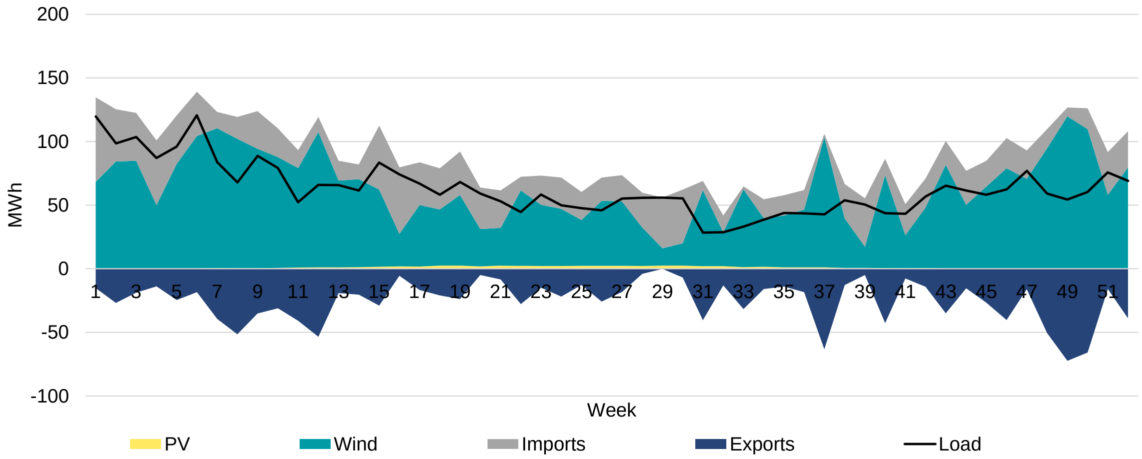

Figure 32: Annual electric supply for the EB-SC in the island of Kökar in 2030

Figure 33 and Figure 34 illustrate the hourly electricity supply profile for the island of Kökar for the first two weeks of January and July in 2030, respectively. Both figures show how **the surplus of electricity production mainly from the wind turbines is exported to the national grid**. The main difference compared to the Ref-SC is a larger electricity exports when electricity surplus is produced mainly by wind turbines.

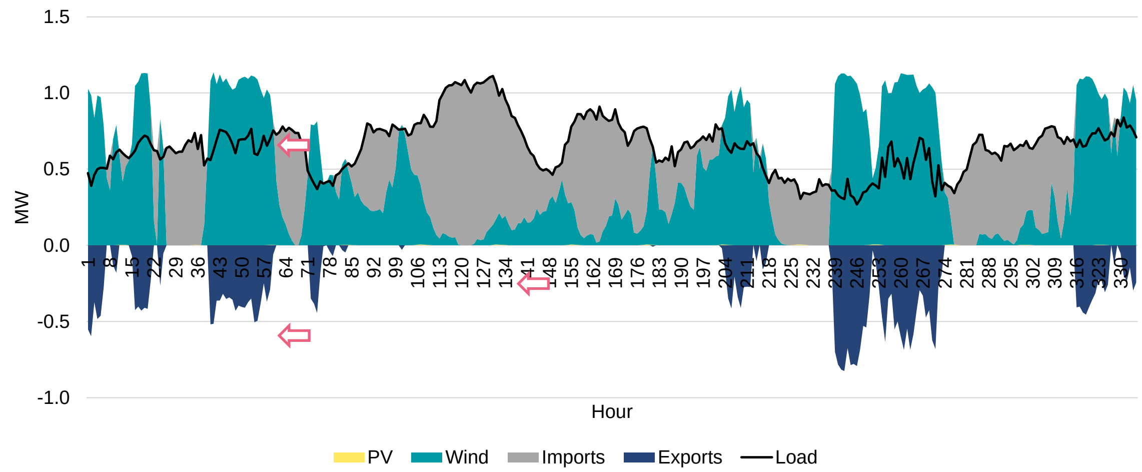

Figure 33: Hourly electricity production in the first two weeks of January according to the EB-SC in the island of Kökar in 2030

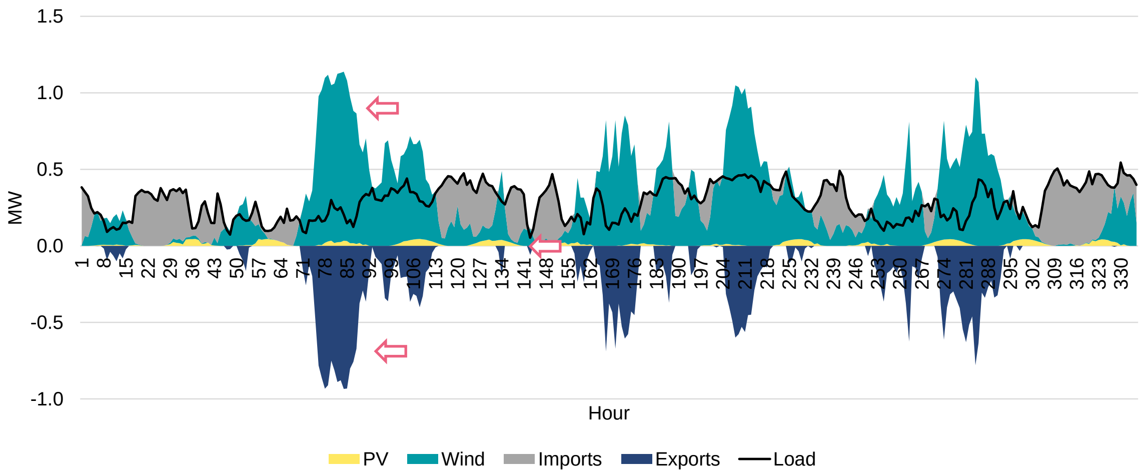

Figure 34: Hourly electricity production in the first two weeks of July according to the EB-SC in the island of Kökar in 2030

HEATING SECTOR

Figure 35 shows the annual heat supply in EB-SC per week in 2030 by different heat production technologies. In the island of Kökar, **heat is produced and consumed locally, hence heat trade with an external network out of the community is not possible**. Heating sector performs in a similar way as for the Ref-SC because no additional assumptions are adopted. Therefore, the total heat production is around 2,610 MWh (including distribution losses) on an annual basis. **Biomass boilers are the main heat source** with 937 MWh followed by geothermal HPs with 913 MWh. The bigger COP of geothermal HPs allows to this technology to generate more heat than air-source HPs even if they have similar electricity consumption.

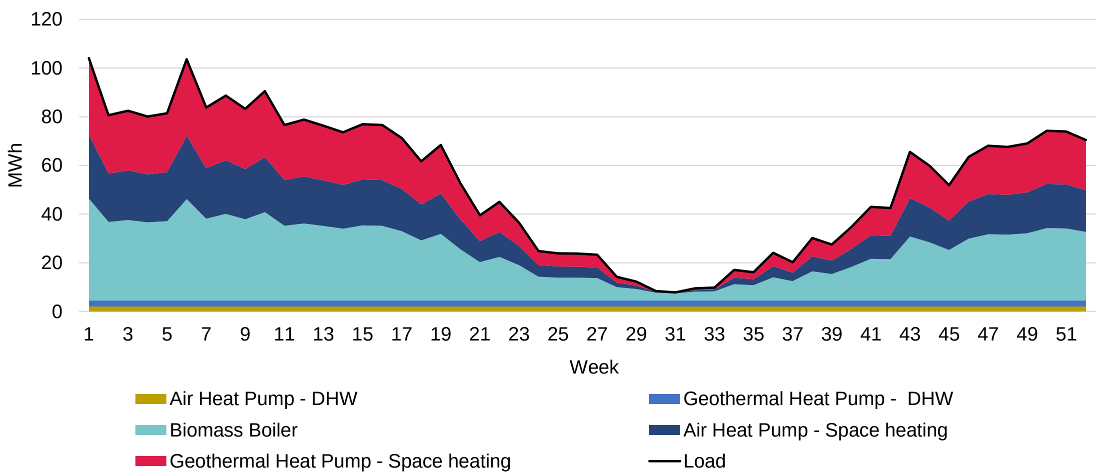

Figure 35: Annual heat production by technologies according to the EB-SC in Kökar in 2030

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Figure 36 and Figure 37 illustrate hourly heat production profiles for the first two weeks of January and July in 2030, respectively. In the same way as Ref-SC, the heat production profile is characterized by a sequence of peaks and valleys during wintertime. This is because **the fluctuation generated by DSM system connected to the HPs in the electricity profile are amplified in the heating profile due to the COP of these technologies**.

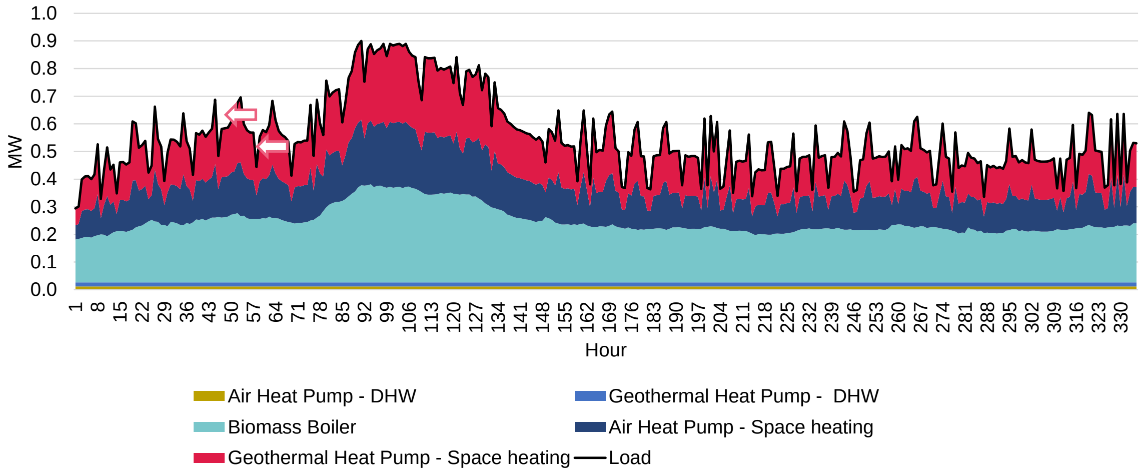

Figure 36: Hourly heat production by technologies in the first two weeks of January according to EB-SC in the island of Kökar in 2030

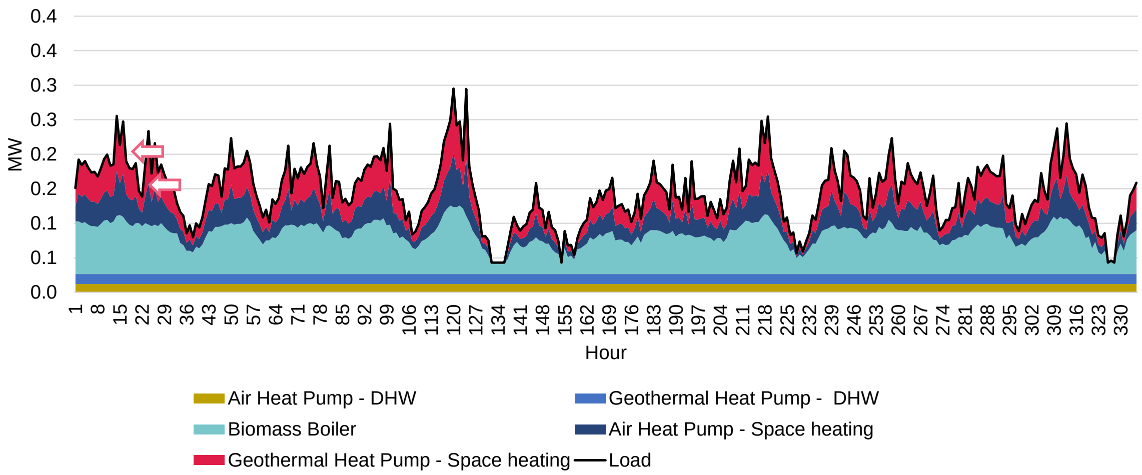

Figure 37: Hourly heat production by technology in the first two weeks of July according to the EB-SC in the island of Kökar in 2030

CO_2 EMMISSIONS

Figure 38 shows the direct and indirect CO_2 emission by sector of the EB-SC scenario in the island of Kökar. The total CO_2 emissions account for 2,743 tons of CO_2, all of them direct emissions. In this scenario all the direct emissions of all the sectors are avoided except the ones related to the transport sector. Indirect emissions from the electricity are also avoided due to the achievement of the electric energy balance in the island. In this sense, there is a reduction of 10% of the overall CO_2 emissions compared to the base year. In this scenario, the main contributors to the CO_2 emissions are the diesel-powered ferry together with the boats.

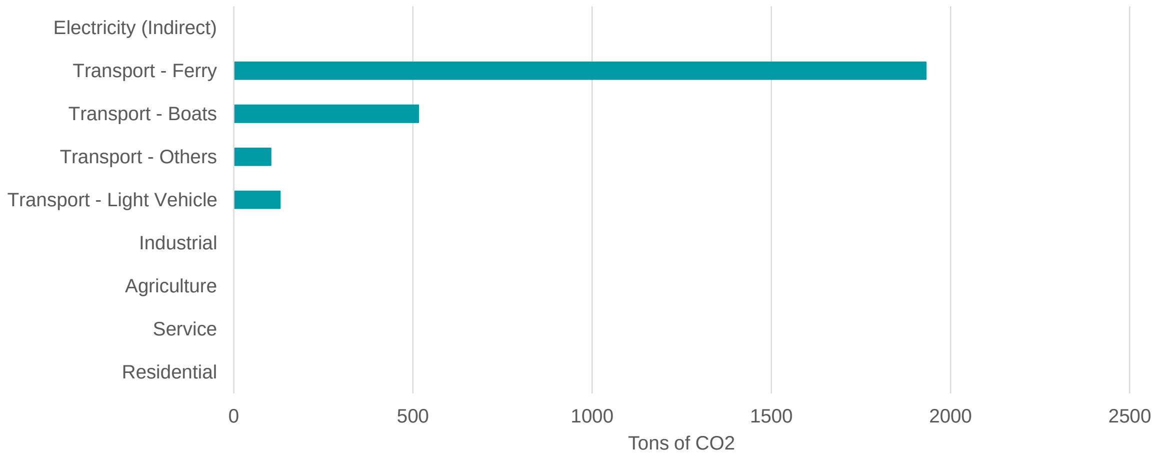

Figure 38: CO_2 emissions by sector of EB-SC scenario in the island of Kökar

3.5.3. TD-SC

Figure 39 shows the overall local heating, electricity, hydrogen production and transmission line capacity in the island of Kökar for the TD-SC. This scenario explores the increase of vRES capacities to achieve electricity balance, as in the EB-SC, together with a further decarbonization of the transport sector in the island of Kökar. This implies the replacement of the current ferries by another one driven by hydrogen, all the light vehicles by e-vehicles and half of the boats by e-boats. In the electric sector, installed PV has the same expansion as in the Ref-SC and the EB-SCs, with an installed capacity of 74 kWp. Nevertheless, wind capacity has a large increase with an installed capacity of 9,440 kW, around nine times more compared to the EB-SC. This is mainly due to the additional electricity demand needed to run the new electrolyser and to keep the energy balance in the island at the same time. In this scenario, it is assumed that **the hydrogen to feed the new ferry is produced locally, making necessary to build an electrolyser and a hydrogen storage** with a capacity of 2.3 MW and 19.1 MWh, respectively. The heating sector performs similarly as for the Ref-SC and the EB-SC. Therefore, **the biomass boiler is the main technology** with 355 kW followed by ground HP, with an installed heat capacity of around 300 kW, and the installed heat capacity of air-source HPs grows up to around 250 kW.

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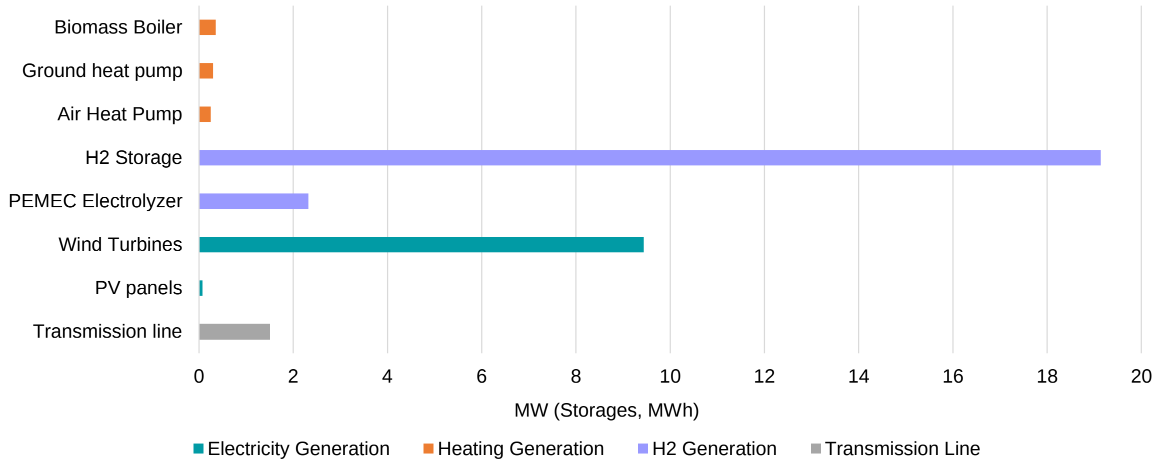

Figure 39: Installed local heat and electricity production capacities by technology and electricity transmission line capacity according to the TD-SC in the island of Kökar in 2030

ELECTRICITY SECTOR

Figure 40 shows the annual electricity demand in the TD-SC by different consumption technologies as well as the impact of the DSM per week in the island of Kökar in 2030. The total electricity demand is estimated at 23,520 MWh (including 3% of electricity distribution losses) on an annual basis, which represents a sevenfold growth compared to the Ref-SC and the EB-SCs. The electrolyser is the main consumer with 19,805 MWh, responsible for 84 % of the total electricity demand. Electric devices and HPs account for an electricity consumption of 3,018 MWh and 362 MWh, and **the DSM has a higher contribution** shifting around 34 MWh of the electric demand. **The higher use of e-vehicles and e-boats produces an increase of the electricity of the demand** rising to 217 MWh and 59 MWh, respectively.

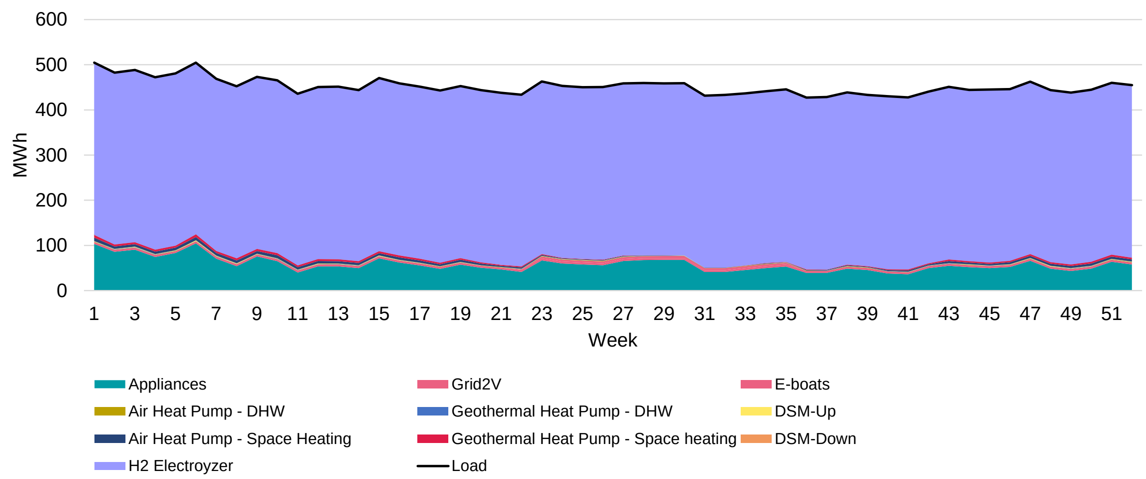

Figure 40: Annual electric demand by technology according to the TD-SC in Kökar in 2030

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Figure 41 and Figure 42 illustrate hourly electricity demand profiles for the island of Kökar for the first two weeks of January and July in 2030, illustrating winter and summer periods, respectively. Both figures show peaks and valleys in the overall electricity profile. **Peaks are produced by the EVs** because the large wind production capacity ensures enough capacity to concentrate the charging of the batteries in few hours with low electricity prices. **Valleys are produced by the reduction of the electricity demand in the electrolyser** to avoid hydrogen production with high electricity prices. This happens when wind electricity production drops or when the import electricity prices are high.

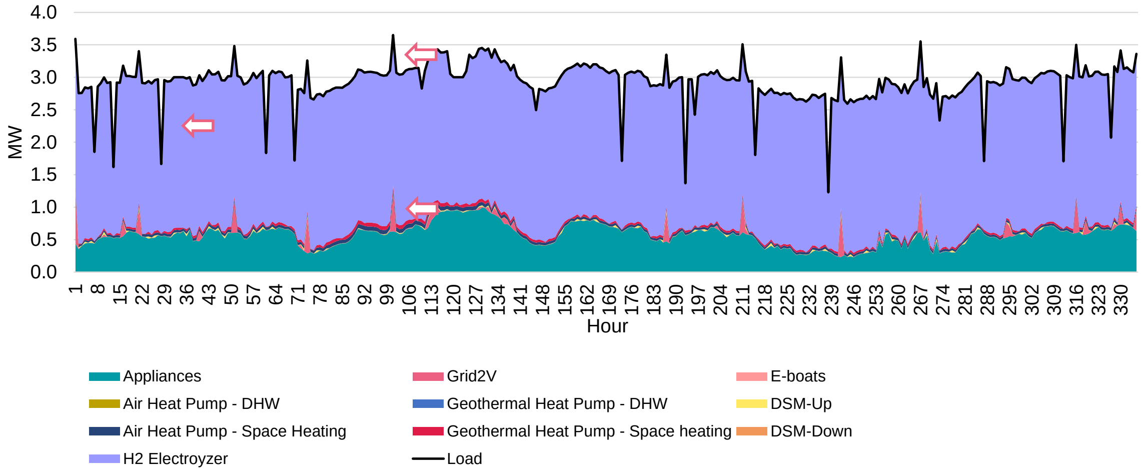

Figure 41: Hourly electricity demand in the first two weeks of January according to the TD-SC in the island of Kökar in 2030

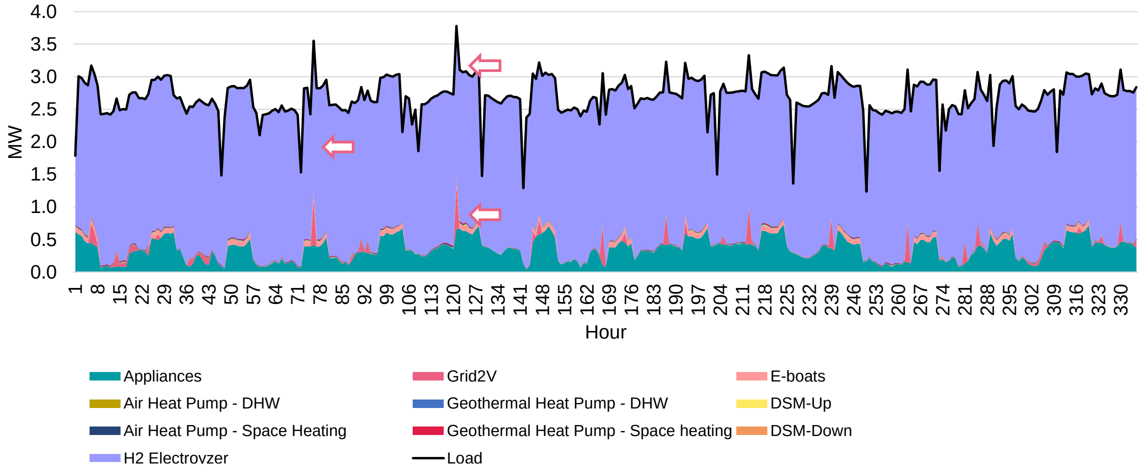

Figure 42: Hourly electricity demand in the first two weeks of July according to the TD-SC in the island of Kökar in 2030

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Figure 43 shows the annual electricity supply per week in the TD-SC from local sources, imports and exports in 2030. Positive values are electricity supply of different options to meet the electricity demand, whereas the negative values represent the electricity that is exported. The annual locally-generated electricity in the island of Kökar is 23,523 MWh similar to the electricity demand (including transmission losses). **As in the previous scenarios, wind electricity production is the main energy source** producing 23,467 MWh of electricity being **PV electricity production negligible** with around 56 MWh in relative terms. The larger local electricity production rises electricity imports and exports compared to the Ref-SC, accounting in both cases for 8,385 MWh to achieve the electric energy balance in the island. This represents a fivefold increase in the electricity imports and a fourteenfold growth of the electricity exports compared to the Ref-SC. However, **the transmission line capacity of 3 MW is not big enough to absorb all the electricity production surplus** which **results in curtailment of wind electricity** at certain moments. This lack of capacity in the transmission line prevents additional electricity exports from the local production to the mainland of around 3,295 MWh.

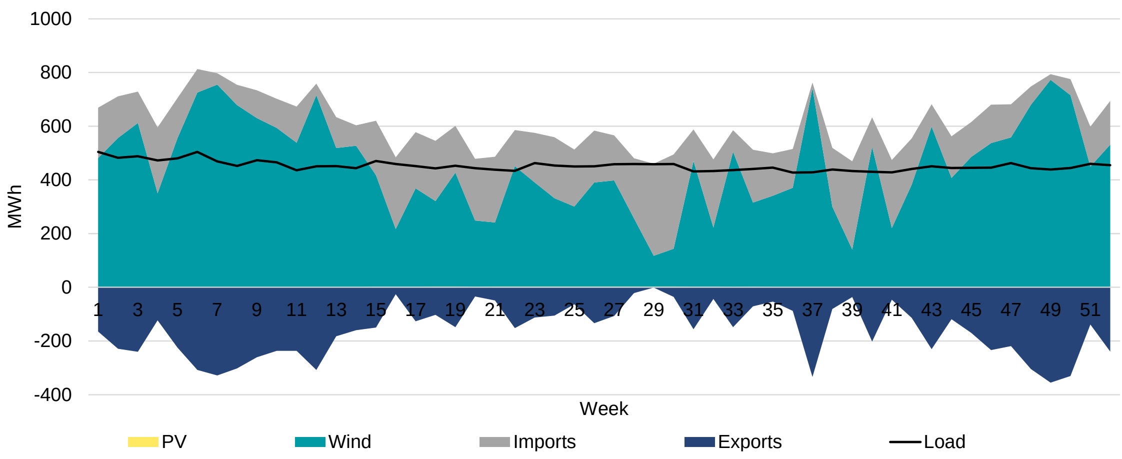

Figure 43: Annual electric supply by technology according to the TD-SC in Kökar in 2030

Figure 44 and Figure 45 illustrate the hourly electricity supply profile for the island of Kökar for the first two weeks of January and July in 2030, respectively. Both figures show how **the surplus of electricity production mainly from the wind turbines is exported to the national grid as well as the limitation of the capacity transmission line that produces curtailments** in the local electricity production technologies. Valleys produced by the reduction of the electricity demand in the electrolyser to avoid hydrogen production with high electricity prices are also shown.

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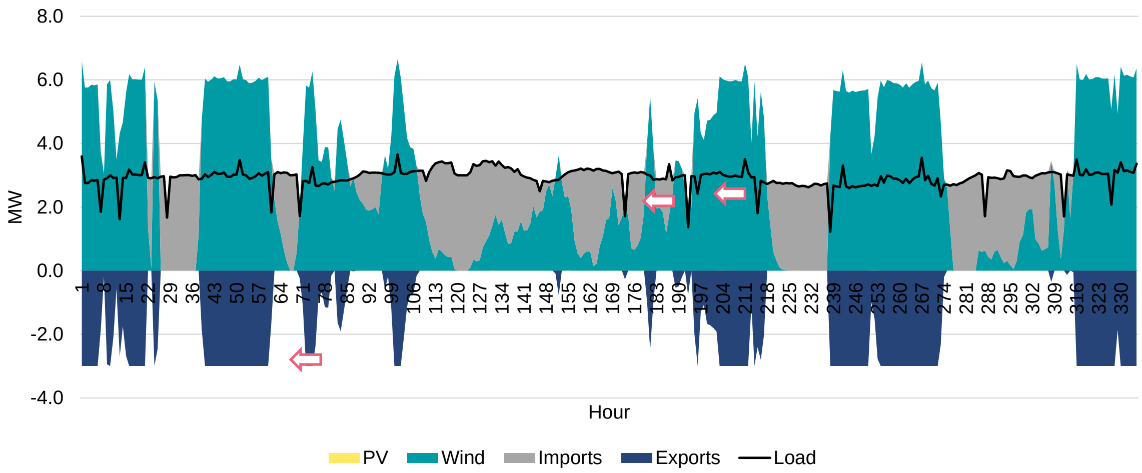

Figure 44: Hourly electricity production in the first two weeks of January according to the TD-SC in the island of Kökar in 2030

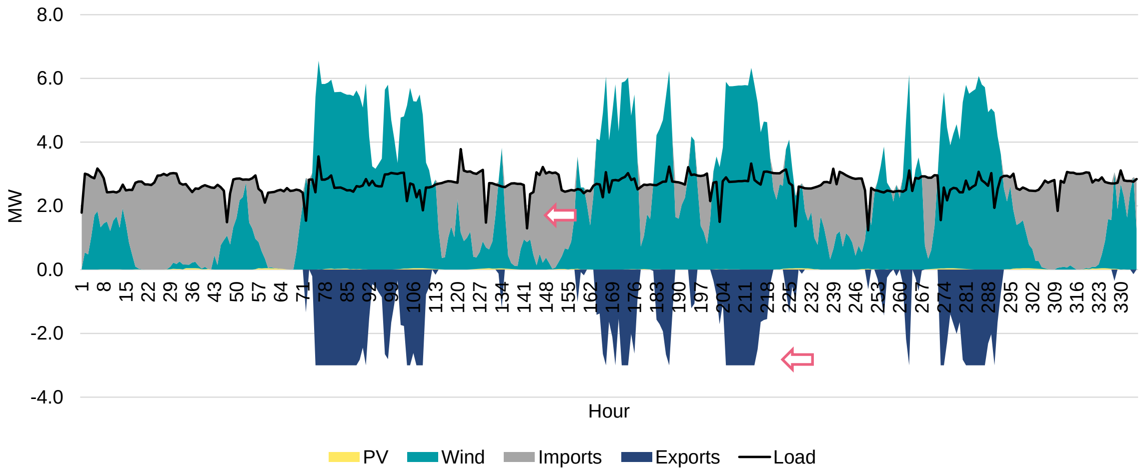

Figure 45: Hourly electricity production in the first two weeks of July according to the TD-SC in the island of Kökar in 2030

HEATING SECTOR

Figure 46 shows the annual heat supply in the TD-SC per week by different heat production technologies in 2030. In the island of Kökar, **the heat is produced and consumed locally, hence heat trade with an external network out of the community is not possible**. The heating sector performs similarly as the Ref-SC and the EB-SCs, as no additional assumptions are adopted. Therefore, the total heat production is around 2,610 MWh (including distribution losses) on an annual basis. Biomass boilers are the main heat source with 937 MWh followed by geothermal HP with 913 MWh. The bigger COP of geothermal HPs allows this this technology to generate more heat than air-source HPs even if they have a similar electricity consumption.

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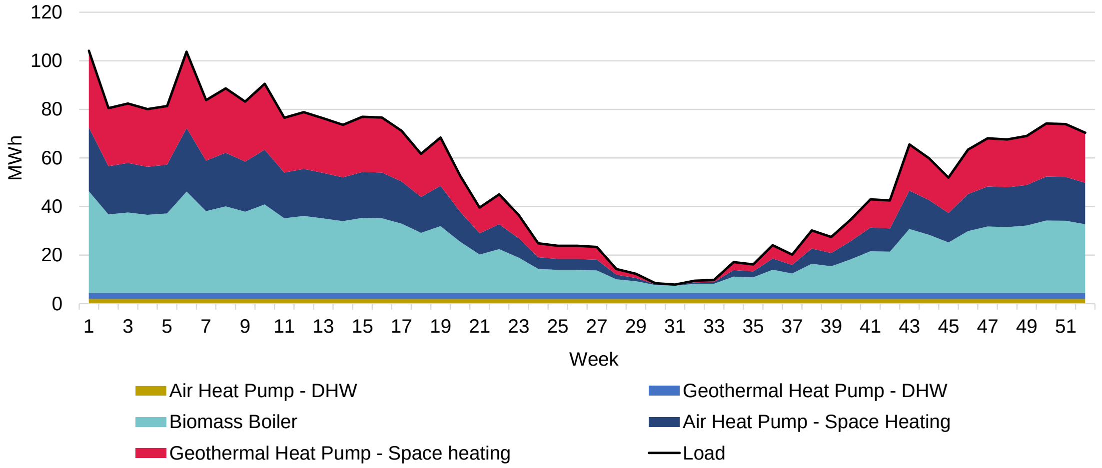

Figure 46: Annual heat production by technologies according to TD-SC in Kökar in 2030

Figure 47 and Figure 48 illustrate hourly heat production profiles for the first two weeks of January and July in 2030, respectively. In the same way as in previous scenarios, the heat production profile is characterized by a sequence of peaks and valleys during wintertime caused by **fluctuation caused DSM system** that amplifies the variation in the electricity profile in the heating profile due to the COP of these technologies.

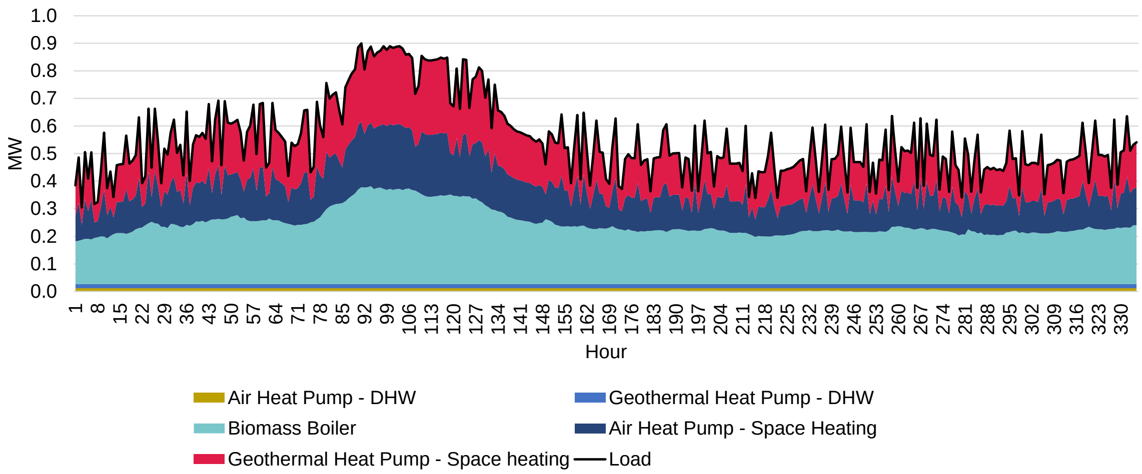

Figure 47: Hourly heat production by technologies in the first two weeks of January according to the TD-SC in the island of Kökar in 2030

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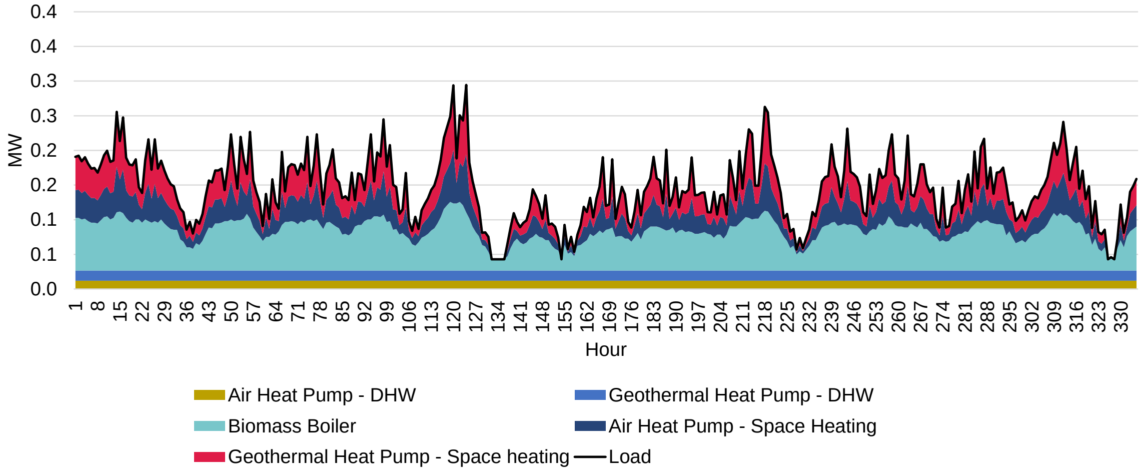

Figure 48: Hourly heat production by technology in the first two weeks of July according to the TD-SC in the island of Kökar in 2030

HYDROGEN SECTOR

In the TD-SC a yearly energy consumption of 14,895 MWh of hydrogen (443 tons of hydrogen) must be generated by an electrolyser located in the island of Kökar. Hydrogen flows among the electrolyser, the hydrogen storage, and the hydrogen load (hydrogen-powered ferry) are exemplified by Figure 49. This figure illustrates the hourly hydrogen production and consumption profiles for the first two weeks of January 2030. The electrolyser located in the island works at a constant load along the year, charging continuously the hydrogen storage. When hydrogen-powered ferry arrives to the harbour is refuelled by discharging the hydrogen storage in combination of additional hydrogen generated by the electrolyser.

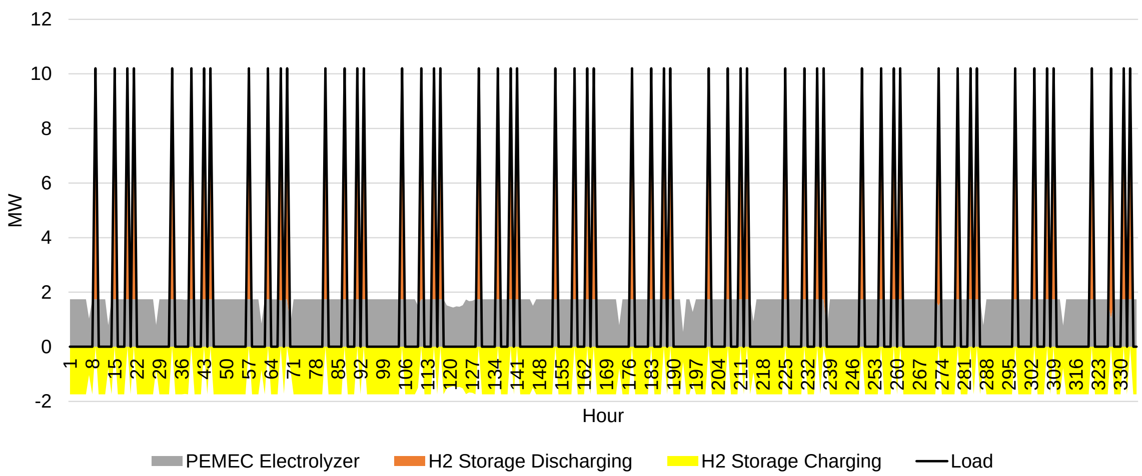

Figure 49: Hourly hydrogen production and refuelling of the hydrogen-powered ferry in the first two weeks of January according to the TD-SC in the island of Kökar in 2030

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CO_2 EMMISSIONS

Figure 50 shows the direct and indirect CO_2 emission by sector of the TD-SC scenario in the island of Kökar. The total CO_2 emissions account for 389 tons of CO_2, all of them direct emissions. In this scenario, all the direct emissions of all the sectors are avoided except the ones related to the transport sector. Indirect emissions from the electricity are also avoided because of the achievement of the electric energy balance in the island. The replacement of diesel-powered ferries by others powered by hydrogen and the higher penetration of e-boats and e-vehicles have a high impact, resulting in a reduction of 87% of the overall CO_2 emissions compared to the base year. The only CO_2 emissions sources are the boats and the other type of vehicles, still driven by fossil fuels.

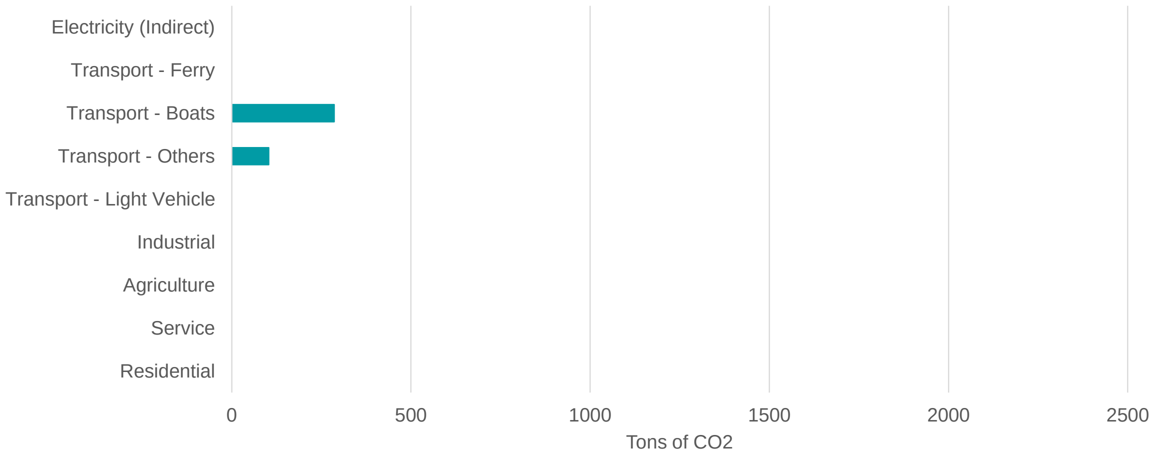

Figure 50: CO_2 emissions by sector of TD-SC scenario in the island of Kökar

3.6. Comparison of scenarios for Kökar

3.6.1. Electric sector

Figure 51 shows the comparison of the electricity capacity of the local production sources and the transmission line of the scenarios and the base year in the island of Kökar. For all the assessed scenarios, electric batteries are not required due the capacity of the transmission line in the respective scenarios, which allows trading with the mainland to balance the electric system. However, in the TD-SC the capacity of the transmission grid is not high enough to avoid curtailment in the electric production technologies. In terms of electricity production, for all scenarios the overall PV installed capacity remains low, accounting for 74 kWp. The main driver for the decarbonization of the electric sector is wind electricity production due to the high number of operation hours of this resource in the island. In this sense, in the Ref-SC scenario the installed wind capacity is around 0.8 MW, growing up to 1.1 MW to achieve the electricity balance in the EB-SC scenario, and rising up to 9.4 MW in the TD-SC scenario to achieve a high level of decarbonization of the transport sector, keeping at the same time the electricity balance in the island

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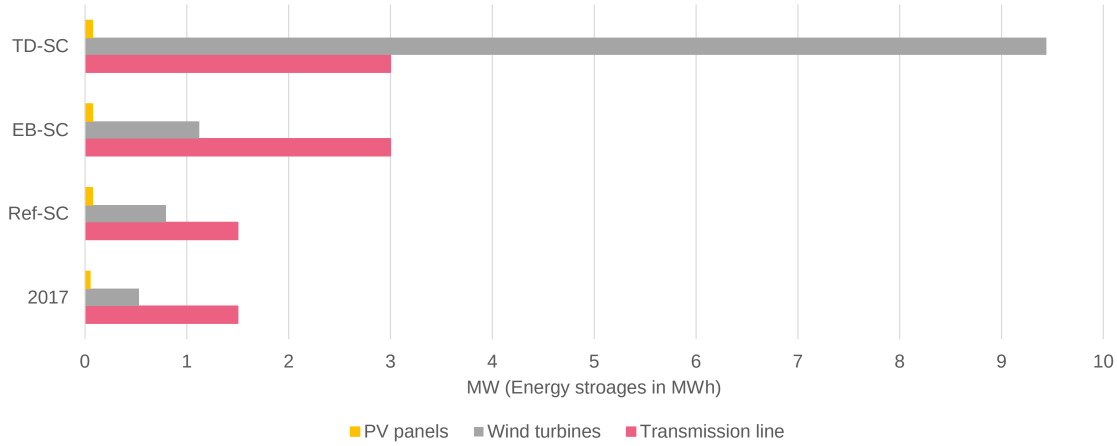

Figure 51: Comparison of the electric capacity of the local electric production sources and the transmission line of the scenarios and base year in the island of Kökar

Figure 52 compares the electricity demand, production, imports and exports of the scenarios and the base year in Kökar. The Ref-SC and the EB-SC perform in as similar way, being the electricity demand around 3.3 GWh. However, in the TD-SC the electricity demand rises up to 23.5 GWh, mainly due to the electrolyser, but also because of the full penetration of e-vehicles and a higher expansion of e-boats. In all the scenarios, wind is the main driver towards the decarbonization of the electric sector. In the Ref-SC, the locally produced electricity is around 2,3 GWh; 71% of the demand. Under this scenario, the annual electricity imports and exports account for 1,6 GWh and 0.6 GWh, respectively. In the EB-SC and the TD-SC, the electricity balance is achieved. In the EB-SC, the local electricity production is 3.3 GWh, same as the electricity demand, being produced almost totally by wind. Electricity imports and exports account for 1,307 MWh, which represents a 16% reduction of imports and a 110% increase of exports compared to the Ref-SC. In the TD-SC, the local electricity production and the demand areboth around 23.5 GWh, being wind the main source. The larger local electricity production rises electricity imports and exports compared to the Ref-SC, accounting both for 8,385 MWh to achieve the electric energy balance in the island.

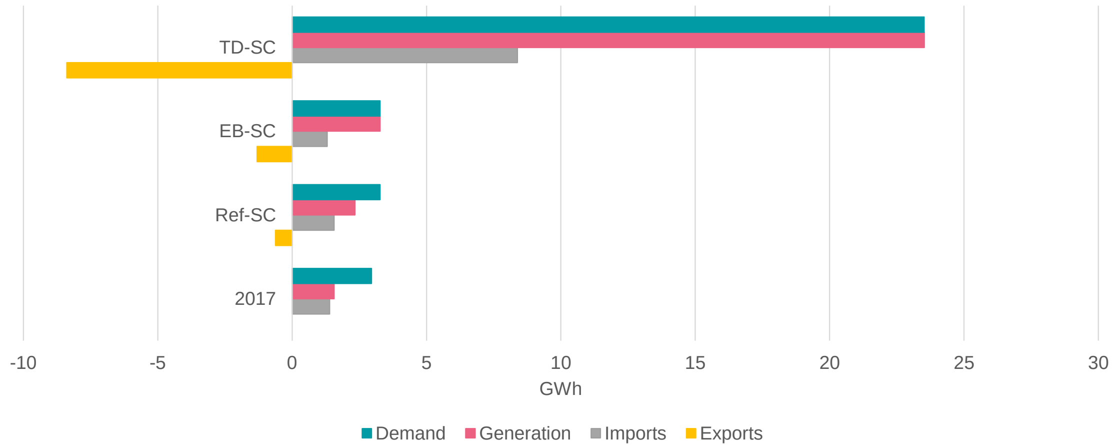

Figure 52: Comparison of the electricity demand, production, imports and exports of the scenarios and base year in Kökar

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3.6.2. Heating sector

Figure 53 shows the comparison of the heating capacity by technology of the scenarios and the base year in the island of Kökar. In all the assessed scenarios the heating sector performs in the same way, and fossil fuels are phased out. There is a general reduction of the heat installed capacity compared to the base year because of the decrease of the heat demand, as well as the replacement of fossil boilers by air-source HPs. HPs (air- and ground-source HPs) constitute the main technology with around 0.55 MW, followed by biomass boilers with 0.35 MW.

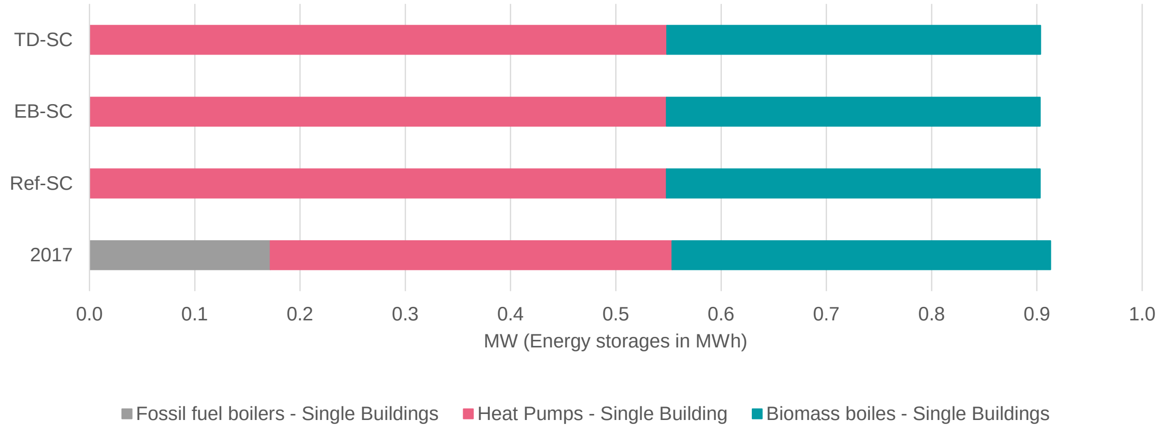

Figure 53: Comparison of the heating capacity by technology of the scenarios and base year in Kökar

Figure 54 shows the comparison of the heating capacity by technology of the scenarios and the base year in Kökar. All the assessed scenarios perform the same, since in all of them the replacement of fossil fuel boilers by HPs was assumed. Thus, the total heat production for the three scenarios is estimated at 2,610 MWh per year. Biomass boilers are the main heat source with 937 MWh followed by geothermal HPs with 913 MWh of heat, while the remaining part is covered by air-source HPs.

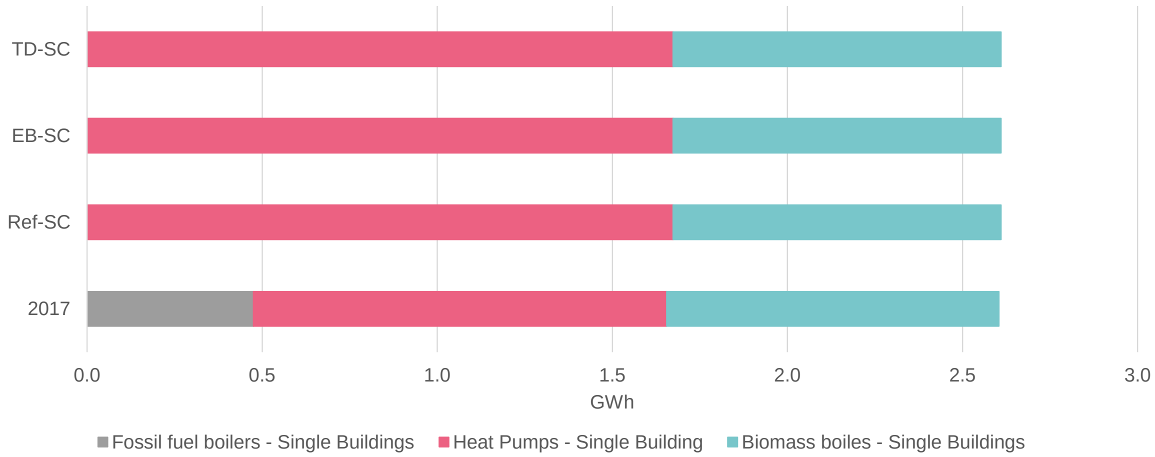

Figure 54: Comparison of the heat production by technology of the scenarios and base year in Kökar

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3.6.3. Transport sector

Figure 55 presents the comparison of the energy consumption of the scenarios and the base year in the island of Kökar. The Ref-SC and the EB-SC scenarios perform equally with an overall energy consumption of around 10.2 GWh, 2% less compared to the base year. This is because of the partial electrification of the transport sector, with the inclusion of e-vehicles and e-boats. In the TD-SC scenario the fuel consumption for the transport sector grows up to around 16.9 GWh due to the need to produce locally the hydrogen to refuel the Hydrogen-powered ferry. Nevertheless, there are additional fossil fuel reductions due to the higher electrification of the vehicles and boats.

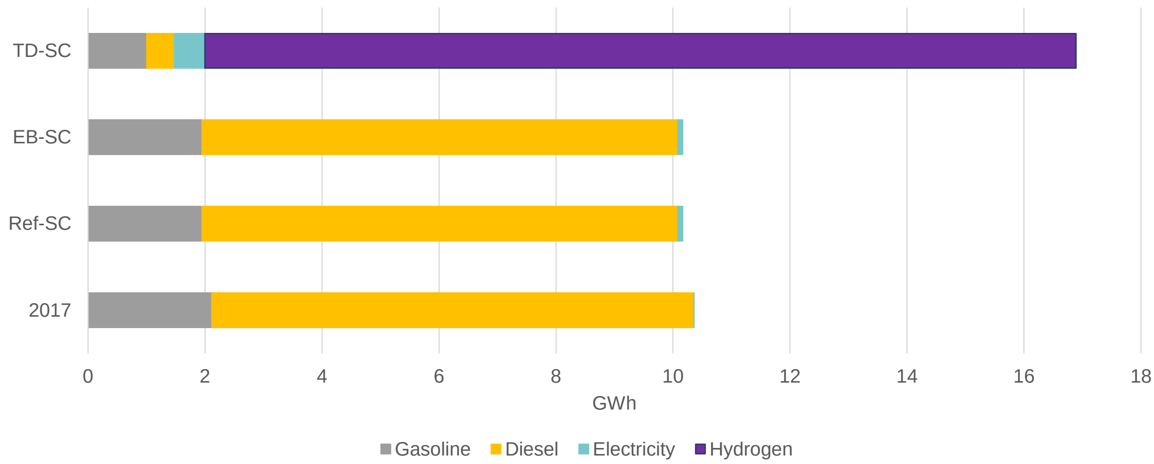

Figure 55: Comparison of the energy consumption of the scenarios and base year in Kökar

3.6.4. CO_2 Emissions

Figure 56 shows the comparison of the CO_2 emissions by sector of the scenarios and the base year in the island of Kökar. In all the assessed scenarios, the direct emissions for all the sectors are avoided except the ones related to the transport sector. In the calculation of the indirect CO_2 emissions for the base year an emission intensity of electricity production of 68 tons of CO_2 by MWh is considered (CETA, 2020). This factor is kept in the scenarios based on the Swedish NECP (European Commission, 2022) together with the low emission intensity of electricity production already existing on the base year (CETA, 2020). In the Ref-SC scenario there is a slight reduction of the overall CO_2 emissions of 3% compared to the base year. This reduction increases within EB-SC scenario up to 10% because the indirect emissions from the electricity are removed, as the electric energy balance in the island is achieved. However, it is in the TD-SC scenario when a reduction of the 87% is achieved due to a higher penetration of e-boats and e-vehicles together with the replacement of diesel-powered ferries by others powered by hydrogen.

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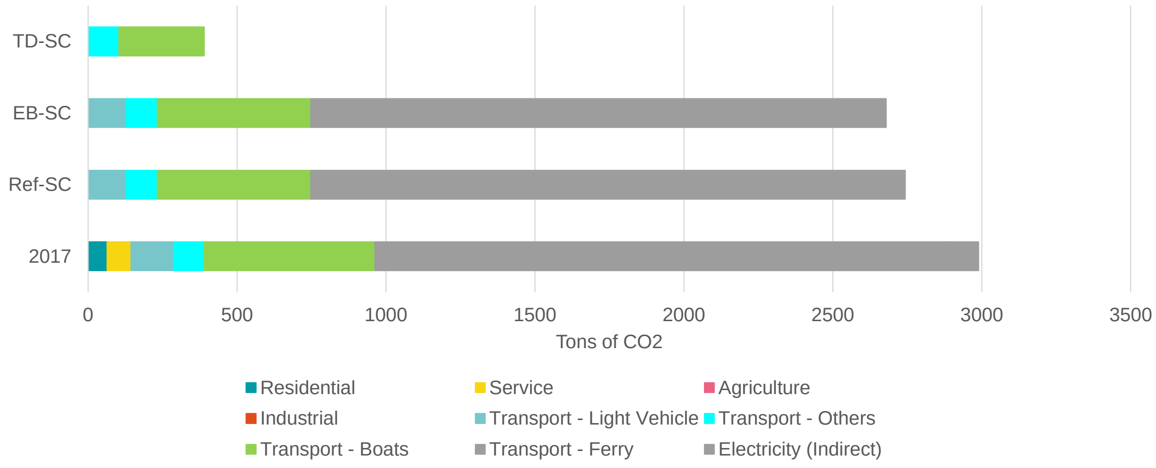

Figure 56: Comparison of the CO_2 emissions by sector of the scenarios and base year in Kökar

3.7. Conclusions

Three scenarios are investigated under the LocalRES project for the island of Kökar: Reference Scenario (Ref-SC), Energy Balance Scenario (EB-SC) and Transport Decarbonization Scenario (TD-SC). The goal of these scenarios is to define in the long-term perspective (2030) different possibilities about how a hypothetical energy community constituting the whole village can perform and support decarbonization of the island.

The overall conclusion is that **wind electricity production is the main technology to achieve the decarbonization target in the island of Kökar**. **The electricity trading between the island and the mainland via the transmission line is fundamental** being necessary to increase its capacity in case that the island wants to achieve their targets in terms of energy balance and transport decarbonization (if the hydrogen-powered ferry is considered).

The expected future scenario represented by the Ref-SC shows that **new capacities PV and wind developments** following the Finnish NECP in combination of local constrains are able cover around 71% of the future electricity energy needs. **Future demand increases due to the expansion of HPs, EVs, and e-boats. Wind production technology is predominant and electric batteries are not required due the high capacity of the transmission line** that allows to trade with the mainland to balance the electric system and avoid bottle necks. **E-boats have a relevant consumption** and can represent one third of the hourly electricity demand during summertime. **DSM and charging of EVs have low impact** on the overall electricity demand profile. However, **DSM can produce high fluctuations in the heating profile** due to the high penetration of HPs in the heating sector in combination of a multiplier effect from the COP of these heating technologies.

In the EB-SC, the electricity balance in the island of Kökar is achieved, and the wind production capacity can increase to around 1.1 MW, 41% more compared to the Ref-SC. The current

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transmission line capacity of 1.5 MW of the island is enough to avoid bottlenecks and curtailment under this case.

The TD-SC shows that **the replacement of the diesel-powered ferry by another one driven by hydrogen causes a sevenfold increase of the electricity demand** in the island compared to the Ref-SC due to the new electrolyser. This infrastructure will represent 84% of the overall electricity demand in the island. To achieve the energy balance under this case, wind production capacity needs to rise to 9.4 MW. However, a capacity of 3 MW in **the transmission line capacity of the island is not big enough to absorb all the electricity production surplus generating curtailments of wind electricity** in certain moments.

In terms of decarbonization, in all the assessed scenarios direct CO_2 emissions for the all the sectors are avoided except the ones related to the transport sector. In the Ref-SC scenario there is slight reduction of the overall CO_2 emissions of 3% compared to base year. This reduction increases in the EB-SC scenario up to 10% because indirect emissions from the electricity are removed as the electric energy balance in the island is achieved. However, it is in the TD-SC scenario when a reduction of 87% is achieved due to a higher penetration of e-boats and e-vehicles, together with the replacement of diesel-powered ferries by others powered by hydrogen.

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4/ Berchidda demo case

4.1. Overall pilot description

The Italian pilot of LocalRES, the village of Berchidda is located on the southern face of Mount Limbara in the Gallura region, in north of Sardinia island (see Figure 57). The village land covers approximately 201 km², and is located at an average altitude of 300 m, surrounded by a wide hilly area in a radius of almost 20 km. Climatic conditions are typical for Sardinia's inland areas, with an annual average temperature of 15°C. Berchidda has 1,792 buildings, mainly consisting of single houses and blocks of flats: over 88% of residential buildings have from 1 to 2 floors above ground.

Figure 57: View of the village of Berchidda

In the village of Berchidda, the population has reduced along the last 20 years from 3,177 inhabitant to 2,636 inhabitants (ISTAT-Istituto Nazionale di Statistica, 2022). This demographic decrease is common to all the towns of the Gallura hinterland and Sardinia, in contrast to an increase of the population of the coastal villages.

The village is the owner of the electricity grid (ring infrastructure) in the town centre and the acquisition of the surrounding rural area is undergoing. The village plans to upgrade the electricity grid with smart grid technologies and to promote innovative solutions along the entire electricity supply chain, involving all stakeholders in the area, having as main objective the creation of one of Europe's first "Local Energy Communities".

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4.2. Current energy characterization of the pilot – Base Year 2017

4.2.1. Annual energy demand assessment

Figure 58 shows the breakdown of the overall final energy demand by fuel and sector in the village of Berchidda, which is estimated at around 25,825 MWh. The selected reference year is 2017 as this year is the latest with available data in terms of energy consumption in the village by sector. Unfortunately, this data only relates to electricity consumption and there is a gap in terms of energy consumption for the remaining fuels to cover all services. Hence, to cover this gap, **it is assumed that the village performs in the same way as Sardinia** (RSE - Ricerca Sistema Energetico, 2020). First, energy values at regional level are scaled down to local level assuming energy consumption by type of building performance for the residential sector, and energy consumption per capita performance for the service and transport sectors. Second, results from the first step are discussed with local experts to adapt them to the local specific conditions of the village of Berchidda. For the remaining sectors, it was identified that there is not energy consumption in the agriculture sector while the industrial sector (Cork factory) only consumes electricity.

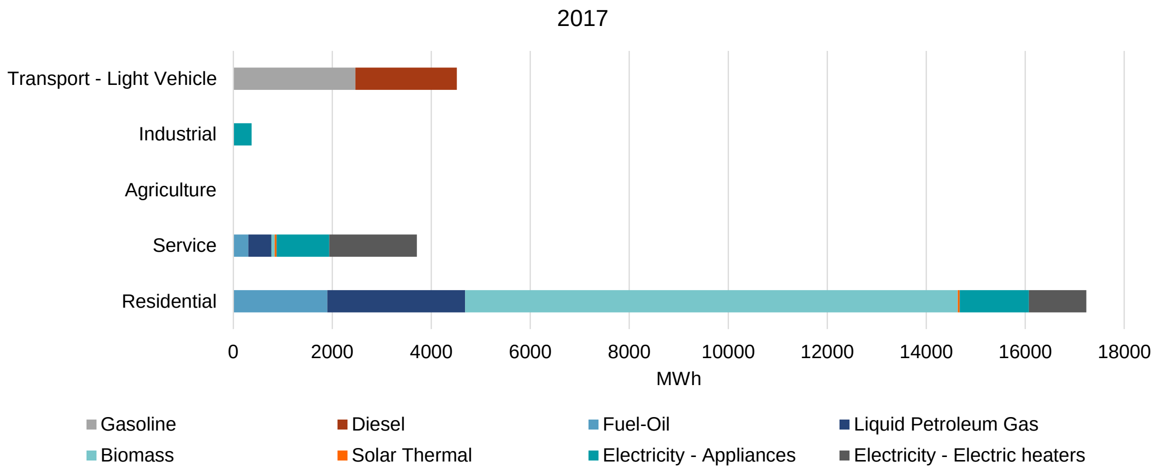

Figure 58: Estimated final energy demand by fuel and sector in 2017 in the village of Berchidda

The residential sector is the main energy consumer with an annual consumption of 17,235 MWh that represents 67% of the total energy consumption. In this sector, **biomass is the main fuel** with 9,955 MWh, being 58% of the total fuel consumption. There is also an important use of electric heaters for DHW that consume 1,164 MWh electricity, representing 45% of the total electricity demand in this sector. **Transport sector, with 4,514 MWh, is the second largest consumer and is driven by fossil fuels only**, as in 2017 there are not EVs available, while gasoline represents 55% of the fuel needs and the rest is diesel. Energy demand for the service sector is 3,707 MWh, where electricity is predominant, sharing 76% of the total. **Electricity is also the main source for space heating** with 1,448 MWh. **Solar panels have a minor contribution to cover DHW demand** with a total heat production of 77 MWh. Finally, **industry sector is the smallest sector** consuming 369 MWh of electricity. No energy consumption is conducted for agriculture sector as it is accounted in the industrial sector.

CO_2 EMMISSIONS

Figure 59 shows the direct and indirect CO_2 emission by sector of the base year in the village of Berchidda. The total CO_2 emissions accounts for 3,772 tons of CO_2, of which 1,225 tons of CO_2 are indirect emissions due to the electricity consumption from the national grid. The remaining are direct emissions from the different sectors. In the calculation of the indirect CO_2 emissions an emission intensity of electricity production of 248 tons of CO_2 by MWh is considered, which is the average values for Italy in the period 2017-2019 (EEA, 2022). This is done to avoid possible fluctuations for 2019 and capture better the current trend. Indirect emissions are the main emission source representing 32% of the overall CO_2 emissions, followed closely by transport and residential sector with 1,194 tons of CO_2 and 1,162 tons of CO_2, of direct emissions that represent 31% and 30% of the overall emissions, respectively.

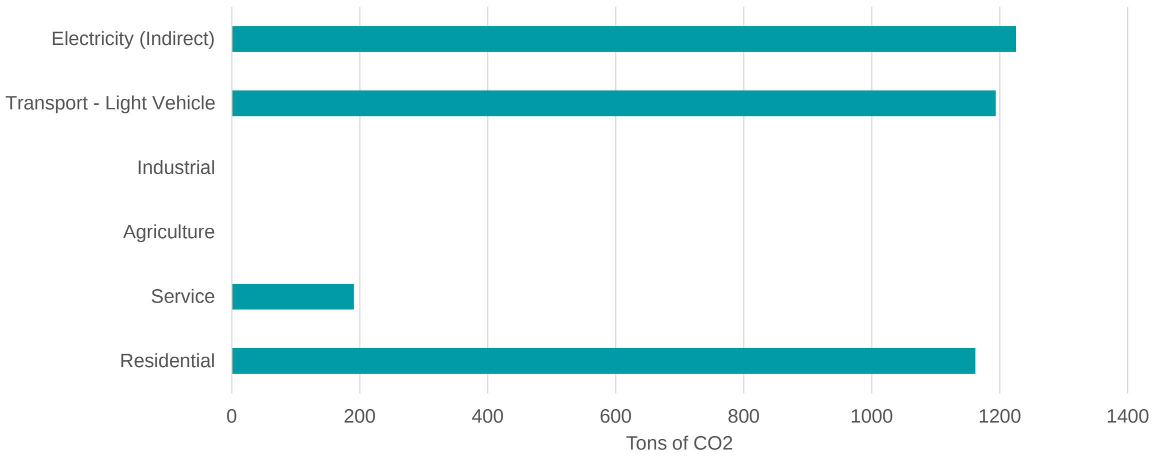

Figure 59: CO_2 emissions by sector of base year in the village of Berchidda

ELECTRICITY DEMAND PROFILE

Figure 60 presents the estimated hourly electricity demand profile in the village of Berchidda. The total annual electricity consumption reaches 5,762 MWh in 2017. For this year, there is only available information about how the electricity demand is split by sector on a monthly basis. In addition, there is only one complete electricity demand profile for Berchidda recorded from the year 2018 with a temporal resolution of 15 minutes. Considering these conditions, **it is assumed that the electricity demand profile in 2017 follows the same trend as in 2018**. Therefore, the electricity demand profile from 2018 is adapted to available information for 2017, i.e. monthly electricity consumption by sector, as well as to an hourly time resolution to match the one used in the Balmorel tool.

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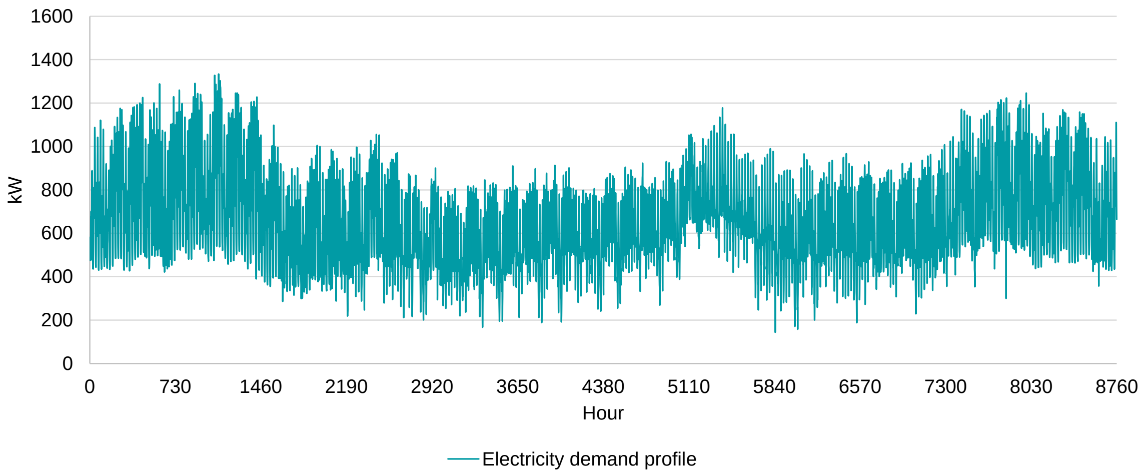

Figure 60: Estimated electricity demand profile for the village of Berchidda

HEAT DEMAND PROFILE – SPACE HEATING AND DHW

The total annual heat demand accounts for 13,862 MWh in 2017. The hourly heat demand profile of the village of Berchidda is shown in Figure 61, which is estimated based on the energy use. There is not information about the hourly load heat profile of the village of Berchidda. In this context, **a synthetic profile is built based on a combination of two single profiles, one that represents space heating and another one that represents DHW**. The profile for space heating is based on the combination of the monthly heating degree days (HDD) profile based on the nearest meteorological station located in the village of Olbia (BizEE, 2022) together with the hourly temperature profile for the village of Berchidda obtained from PVGIS (JRC-European Commission, 2022). **The DHW profile follows the general DHW hourly resolution profile developed within the European REACT project** (REACT project, 2018). Finally, both profiles are normalized, weighted, and summed up to estimate the overall hourly heat demand profile at municipal level. It is estimated that **the space heating consumes 84% of the total heat demand**.

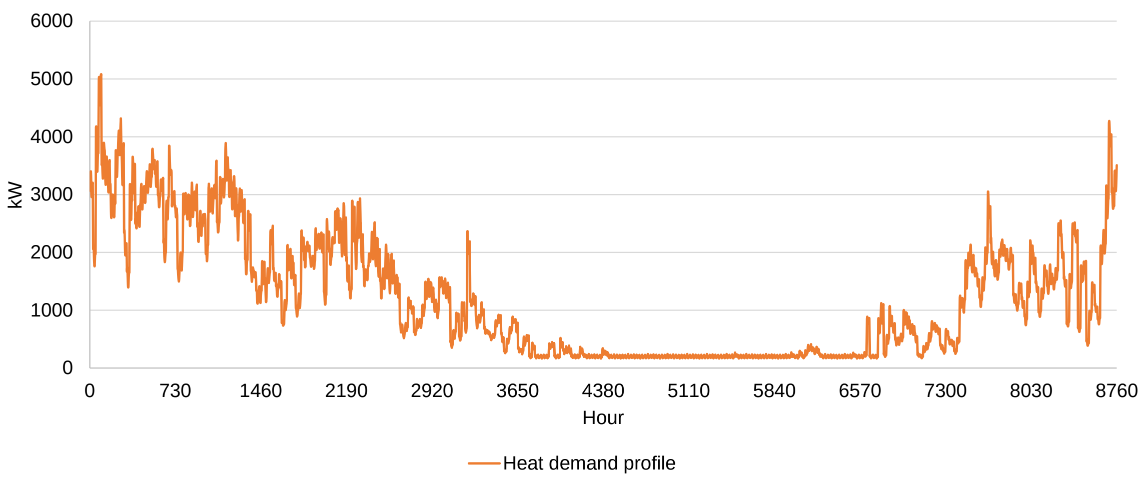

Figure 61: Estimated heat demand profile for the village of Berchidda

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OTHER ASSUMPTIONS CONCERNING THE TRANSPORT SECTOR

Transport sector is dominated by gasoline and diesel vehicles, 437 and 403 vehicles in 2017, respectively. It is assumed that the mobility performance follows the one in Sardinia. In this context, annual passenger-kilometre (pkm) can be estimated around 12,625 pkm (RSE - Ricerca Sistema Energetico, 2020) and annual vehicle-kilometre (vkm) around 10,520 vkm, with an average of 1.2 passenger per vehicle (Surecity Project, 2019).

4.2.2. Local heat and electricity production capacity

Figure 62 shows the local heat and electricity production, as well as the electricity transmission line capacity of the village of Berchidda in 2017. In this year, **the village of Berchidda accounted for 67 PV installation plants with a total capacity of 608 kWp**. The two PV plants located in the cork factory and the cellar are the largest ones with an overall capacity of 350 kWp, accounting for 57% of PV capacity installed at Berchidda. These plants generated 821 MWh with 1350 FLH (full-load hours) in this year. The electricity transmission line that connects the village of Berchidda to the national grid has an effective capacity of 1.5 MW, enough to cover the winter and summer peaks. Nevertheless, **along the years there are punctual losses in the effective capacity of the transmission line that produce a mismatch between electricity demand and supply**. In the heating sector, as previously mentioned, biomass heater is the most relevant technology with around 3.25 MW of installed capacity. Solar thermal panels supported by thermal storage play a minor role with an installed heat capacity of 0.06 MW.

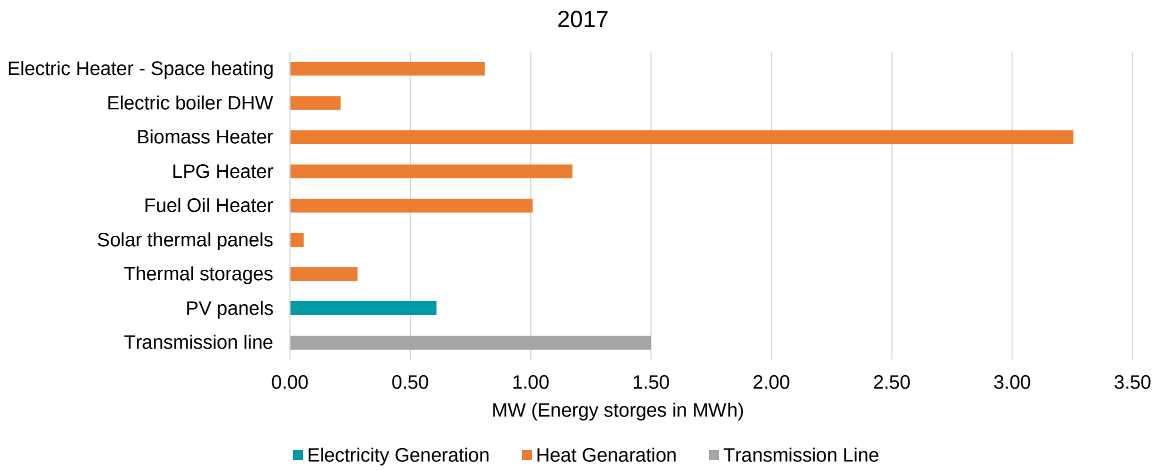

Figure 62: Local heat and electricity production capacity and electricity transmission line capacity for the village of Berchidda

ELECTRICITY PRICES PROFILE

The profile of electricity prices or Italy in 2030 is presented in Figure 63. **The electricity prices for Italy in 2030 are based on EU28-Balmorel model** as mentioned in section 2.3. It is expected that Italian electricity prices will have a high fluctuation due to the increase of vRES connected to the national grid, with an average electricity price around 50.6 €/MWh in 2030. In this context, Italian **electricity prices, as well as the local the transmission line capacity** that connects the village of Berchidda to the national grid, **determine how the community interacts with its national market**, more precisely how the exchanges (imported/exported electricity) take place under a least-cost solution framework.

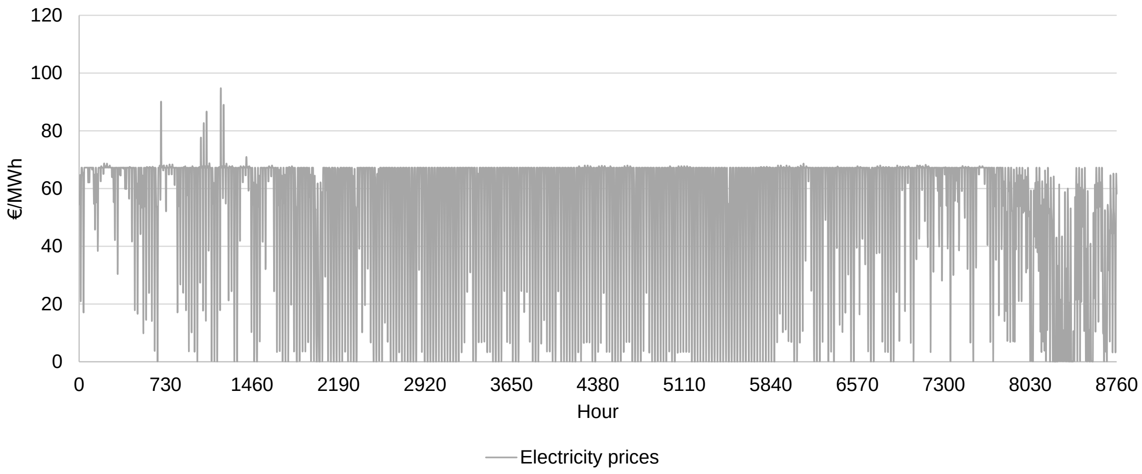

Figure 63: Estimated electricity prices profile for Italy in 2030

SOLAR PROFILE

Figure 64 shows the hourly electricity production profile for PV panels in the village of Berchidda. This profile was built using the PVGIS tool (JRC-European Commission, 2022) taking as reference a crystalline silicon PV panel with a nominal power of 1 kWp and solar data from 2016. This PV profile is also used to define the thermal energy production from solar thermal panels.

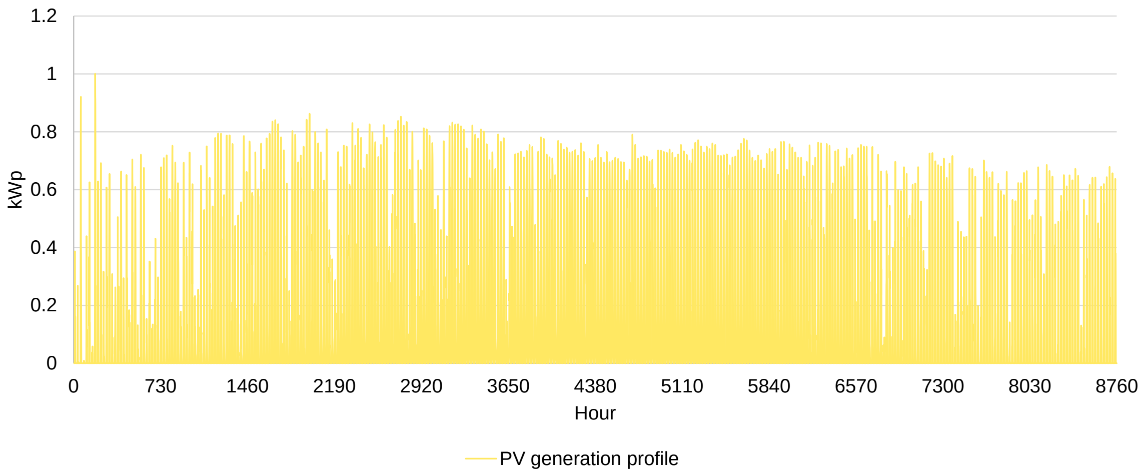

Figure 64 Estimated electricity production profile for PV panels in the village of Berchidda (normalized to 1 kWp)

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4.3. Scenario definition

Three scenarios are analysed within the LocalRES project for the village of Berchidda. The goal of these scenarios is to define the least-cost solutions for different possibilities in the long-term perspective (2030) about how the establishment of a hypothetical energy community including all the community can perform and support the energy decarbonization in Berchidda. In this analysis, the impact of flexibility measures such as DSM, smart charging for EVs, energy storage, HP as well as the use of PV panels is explored in each scenario. These scenarios were built together with the local stakeholder to reflect their view about how the energy transformation can be in the pilot:

- ***Reference Scenario (Ref-SC):*** In this scenario, the village concentrates their efforts in **replacing part of the fossil fuel heating systems by electric HPs and promote the use of EVs**. This scenario also includes the **increase of vRES** capacities (mainly PV) as well as flexibility measures (smart charging for EVs, DSM and energy storage such as batteries and thermal energy storage).
- ***Blackout Scenario (BK-SC):*** In this scenario, the village keeps their effort in replacing part of the fossil fuel heating systems by electric HPs and promoting the use of EVs in the same way as for the Ref-SC. In addition, it is explored **how flexibility measures and local resources can support the mitigation of blackout events and reduce the dependence** on the national transmission grids. The black-event duration was considered 1 hour to be conservative, as these events typically have a lower duration.
- ***100% Electrification Scenario (ELC-SC):*** In this scenario, the village explores **the full electrification of all economic sectors**. Therefore, all the heating boilers are replaced by electric HP and all the vehicles become EVs. This scenario also explores the **new dependence on the national grid in case of 100% electrification, as well as utilization of local resources and required flexibility measures**.

Table 4 summarizes the technical description for the village of Berchidda´s scenarios. For all the scenarios the maximum capacity for PV and electric batteries are considered 3MW and 1 MWh respectively. On the one hand, in the Ref-SC and the BK-SC the replacement of fossil fuel boilers by electric HPs is conservative, being limited to only 50% of the fossil fuel boilers. On the other hand, **the penetration of 10% of EVs with smart charging is high compared to the national target** due to the high interest of the Municipality of Berchidda to promote this technology. In these two scenarios, **EVs include smart charging,** being able to charge the batteries according to the local conditions of the grid and the electricity prices. In the ELC-SC, this goes further, as the EVs also allow the batteries to be discharged to the electricity grid (V2G) in case of need.

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Table 4: Scenario characteristics in 2030 for Berchidda demo case

	Ref-SC	BK-SC	ELC-SC
Max. allowed PV	Up to 3 MW	Up to 3 MW	Up to 3 MW
Max. allowed electric batteries	Up to 1MWh	Up to MWh	Up to 1MWh
Heat pumps	Replace 50% of fossil fuel heating boilers	Replace 50% of fossil fuel heating boilers	Replace 100% of fossil fuel heating boilers
DSM	Available	Available	Available
Solar thermal	Available	Available	Available
E-vehicles	10% of vehicles	10% of vehicles	100% of vehicles
Type of e-charge	Smart charging	Smart charging	V2G
Transmission capacity to national grid	1.5 MW	Minimized	Minimized
Blackout event	N/A.	1 hour	N/A.

4.4. Energy demand projection in 2030

Several drivers and assumptions are required to establish and to estimate the forecasted energy demand of the village of Berchidda by 2030.

The residential sector is the largest energy consumer sector. As for Kökar, **the drivers to estimate the future DHW and electricity demand are based on population forecasting, while space heating demand is linked to the refurbishment rate of buildings**. It is expected that the population in the village of Berchidda will reduce following the current trend of the area. This implies that the population decreases around 8% in 2030 moving from 2,668 inhabitants in 2020 to 2,441 inhabitants (ISTAT-Istituto Nazionale di Statistica, 2022). The effect of the increase of air-conditioning systems to cool down the buildings during the summer period is also assessed. In 2017, electricity consumption by air-conditioning system was around 172 MWh, which represents around 23% of the electricity consumption during the summer period. In 2030, around 10% increase of these systems is expected, implying a future consumption of around 189 MWh. Despite the number of buildings remain the same in 2030, the impact of the refurbishment in buildings will reduce the heat demand for space heating. This refurbishment rate is assumed considering the current trend in Sardinia, which means around 10% reduction of current heat demand (RSE - Ricerca Sistema Energetico, 2020).

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In the service sector, it is assumed that the **future energy demand for public services, such as public lighting, remains the same in 2030. However, the energy demand for private services is driven by the population forecast, so it will decrease**. This is characterized by small local businesses in the village of Berchidda, such as groceries or bakeries, whose level of activity depends on the available local population.

The future energy demand for transport sector also follows population´s forecast, as it is assumed that the annual vehicle-kilometre (vkm) with an average of 1.2 passenger per vehicle remains the identical. Finally, **energy demand in the industry and agriculture sectors remain same**, as no changes are expected in the future of these sectors.

Accordingly, **two future energy demand scenarios** named DMD-Ref and DMD-ELC for the different energy sectors are estimated for 2030. These scenarios are built by combining the drivers to estimate future demand together with the specific needs of the sectors. Furthermore, they consider scenario specifications as well as the impact of shifting to more efficient technologies.

Figure 65 shows the DMD-Ref demand scenario, which is considered in the case of the Ref-SC and the BK-SC to capture the 10% of EVs penetration and the 50% replacement of fossil fuel boilers by electric HPs.

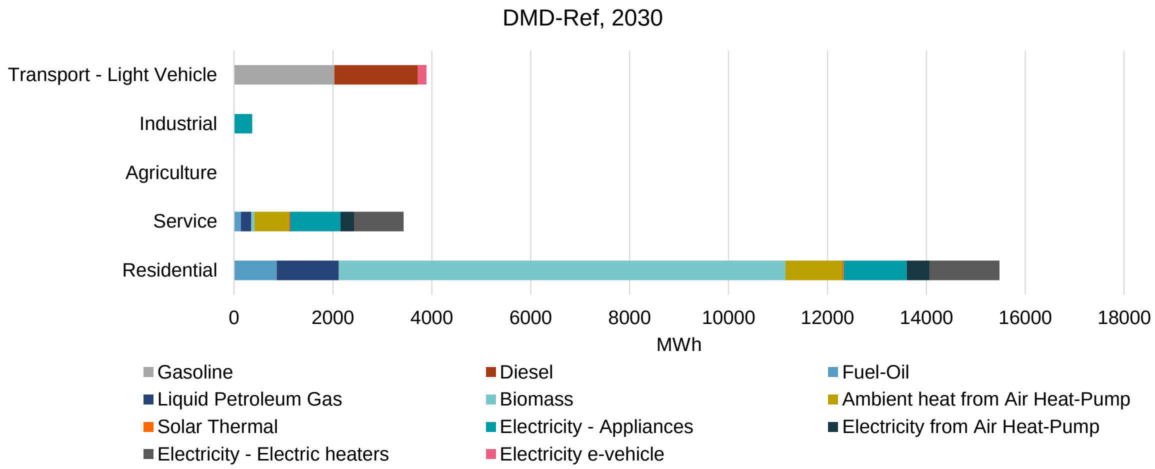

Figure 65: DMD-Ref demand scenario in 2030

DMD-Ref considers an overall fuel demand of 23,167 MWh in 2030 (without electricity distribution losses) that represent 90% of the energy consumption compared to 2017. This is due to the general reduction of the population and building refurbishment in residential buildings as well as the use of more efficient technologies. Due to the electrification of heating and transport sectors, electricity demand grows to 5,993 MWh representing 26% of the total energy demand.

The residential sector remains as the largest energy sector with a total fuel consumption of 15,479 MWh, representing a 10% reduction compared to 2017. **Biomass is still the main energy source** with 9,029 MWh of fuel consumption followed by air-source HPs with 1,601 MWh, of which 457 MWh is accounted for electricity and the remaining part for the extraction of heat from the ambient air.

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The service sector accounts 3,430 MWh of fuel consumption in 2030 that represents a 7% reduction compared to 2017. Air-source HPs in this sector generate 958 MWh; 28% of the total fuel demand.

There is also **a reduction in fuel consumption in transport sector**. In 2030, 77 EVs are expected to be in place with a consumption of 173 MWh. The use of this technology has a high impact on the fuel dependence, as EVs have a higher efficiency compared to ICE vehicles. Finally, the electricity consumption in the industry and agriculture sectors remain the same compared to 2017.

Figure 66 presents the DMD-ELC scenario. This scenario refers to the energy projections for the ELC-SC, where a full electrification of the village of Berchidda is foreseen, replacing 100% of the heating boilers by electric HPs and vehicles by EVs.

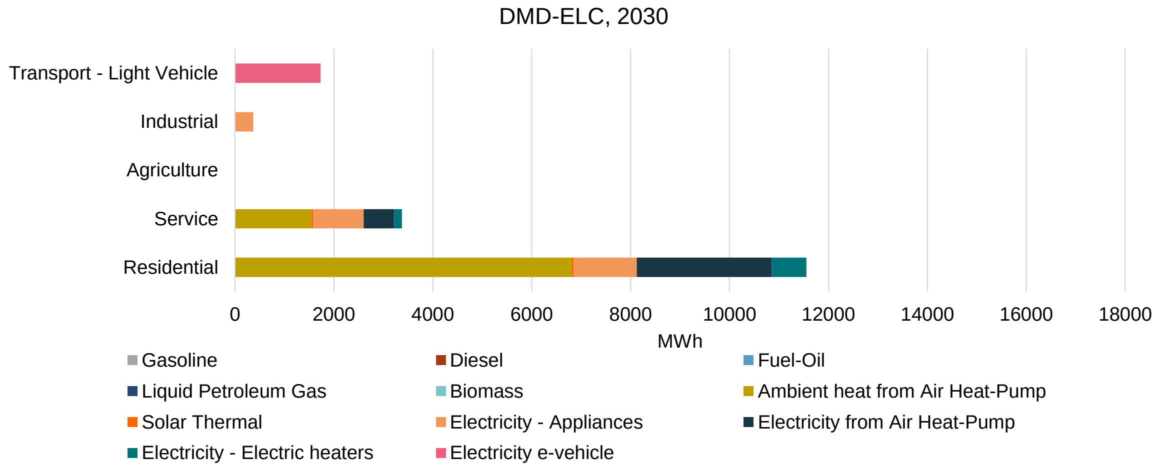

Figure 66: DMD-ELC demand scenario in the village of Berchidda in 2030

The DMD-ELC scenario implies an overall fuel demand of 17,027 MWh (without electricity distribution losses), which represents 66% of the overall fuel demand of 2017. This is mainly due to the higher efficiency of EVs and electric HPs. Due to the full electrification of heating and transport sector, electricity demand grows up to 8,601 MWh, with a share of 51% of the total energy demand.

The residential sector remains the main energy sector with a total consumption of 11,554 MWh, this amount represents a reduction of 33% compared to 2017. Air-source HPs are the main contributor to this reduction. This technology consumes 9,538 MWh of fuel (ambient heat and electricity), of which 2,725 MWh is electricity.

The service sector accounts for 3,374 MWh of fuel consumption, that represent a 9% reduction of the fuel demand compared to 2017. Also, the impact of **the utilization of air-source HPs is essential to understand this reduction**.

In 2030, it is expected that 768 EVs will be operating with an electricity consumption of 1,729 MWh, reducing up to 62% the fuel needs compared to 2017. This is due to the higher efficiency of EV compared to ICE-vehicles. Finally, industry and agriculture sectors consume the same amount of electricity as in 2017.

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4.5. Scenario results and discussion

In this section the simulation results of the Ref-SC, BK-SC and ELC-SC are presented. The results address how electricity and heating sectors in the village of Berchidda are covered by local energy resources and production technologies as well as by different flexibility measures such as storage, power exchange (imports/exports) and DSM.

4.5.1. Ref-SC

Figure 67 shows the overall local heating and electricity production and transmission line capacity in the village of Berchidda for the Ref-SC. In this scenario, **PV has a high increase** with an installed capacity of 2,110 kWp. In parallel, 0.4 MWh of **electric batteries are required to balance the electric system** taking advantages of the electricity surplus of PV panels.

In the heating sector, there is a **general reduction of the installed heating capacity** compared to 2017 because of the decrease in heat in 2030. **Biomass boiler is the main technology** with 2.95 MW followed by air-source HPs for space heating with an installed heat capacity of 1.4 MW. Solar thermal panels as well as thermal storage that is used to balance its production with the consumption remain similar as in 2017.

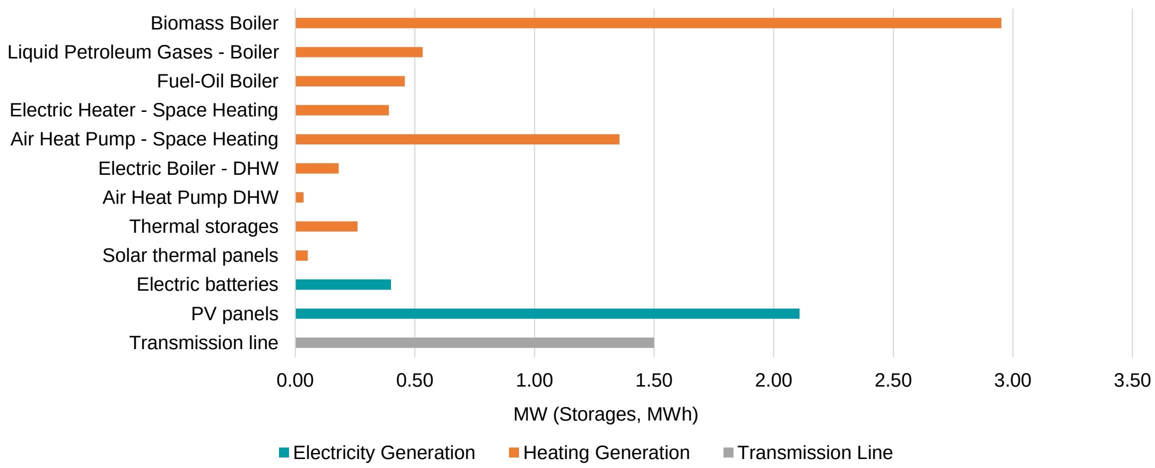

Figure 67: Installed local heat and electricity production capacities by technology and electricity transmission line capacity according to the Ref-SC in the village of Berchidda in 2030

ELECTRICITY SECTOR

Figure 68 shows the annual electricity demand in the Ref-SC by different consumption technologies as well as the impact of DSM per week in the village of Berchidda in 2030. The total electricity demand is estimated at 6,190 MWh (including 3% of electricity distribution losses) on annual basis. **Electric appliances are the main electricity consumers** with 3,330 MWh followed by electric boilers for DHW with 1,282 MWh that represents respectively 54% and 21% of the total electricity demand. Electricity consumption for space heating (air-source HPs and electric heaters) accounts

1,328 MWh. However, the electricity demand for space heating in summertime is negligible concentrating this demand during wintertime. The electricity demand for this purpose can represent up to 46% of the electricity demand in some weeks of the year, for example, in the first week of the year. DSM can shift around 87 MWh of the space heating demand generated by electric devices. Finally, electricity consumption of air-source HPs for DHW accounts for around 72 MWh.

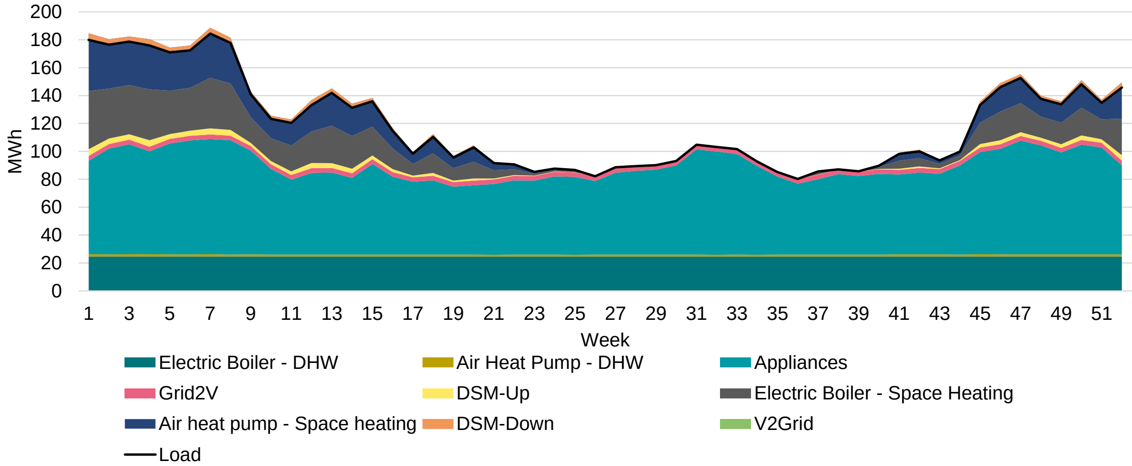

Figure 68: Annual electricity demand by technology according to the Ref-SC in Berchidda in 2030

Figure 69 and Figure 70 illustrate hourly electricity demand profiles for Berchidda for the first two weeks of January and July in 2030, representing winter and summer periods. Figure 69 shows that **DSM allows reducing the electricity peak (DSM-Down) during the winter period** by shifting the heat load of the air-source HPs for space heating, which is necessary due to the limitation of the transmission line capacity of 1.5 MW. In both figures, the **smart charging of EVs also has an impact on the overall electricity demand profile** as the charging of EVs takes place during hours with lower electricity price hours.

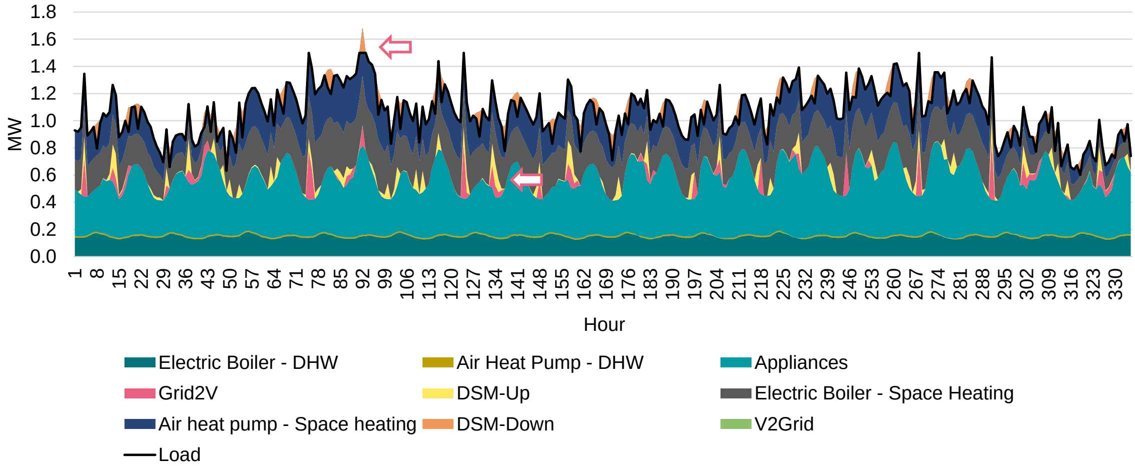

Figure 69: Hourly electricity demand in the first two weeks of January for the Ref-SC Berchidda in 2030

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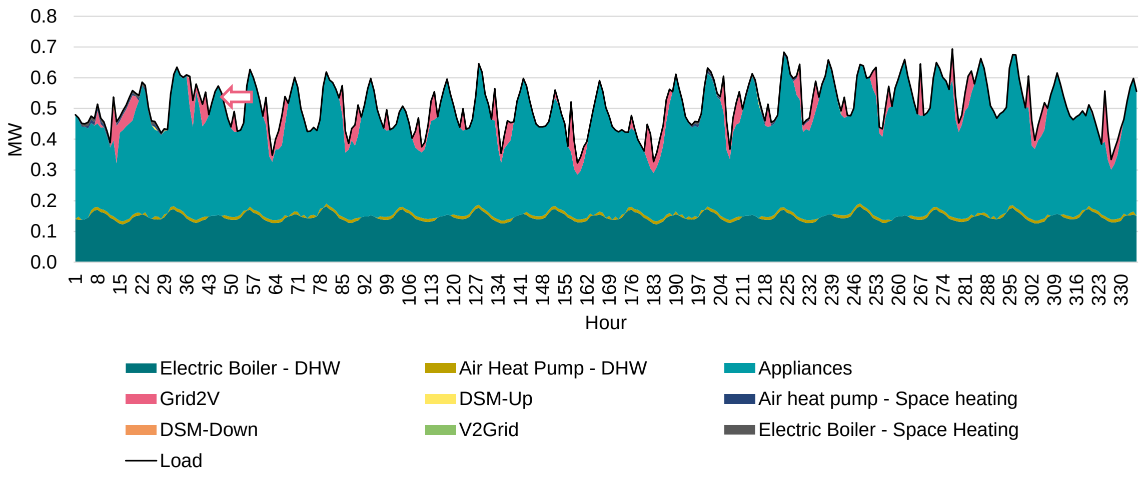

Figure 70: Hourly electricity demand in the first two weeks of July for the Ref-SC in Berchidda in 2030

Figure 71 shows the annual electricity supply per week in the Ref-SC from local sources, import and exports as well as charging and discharging of batteries to balance the electricity system in 2030. Positive values represent electricity supply from different options to meet the electricity demand, whereas the negative values represent the electricity that is either stored in batteries or exported. The annual locally-generated electricity in the village of Berchidda is 2,642 MWh the equivalent to 43% of the total electricity demand (including transmission losses) and it is generated by PV only. Annual electricity imports are 4,352 MWh, where **highest dependence on electricity imports takes place during the winter period, when the lowest local electricity production is combined with the highest electricity demand due to the electricity consumption for space heating**. In fact, during the first week of January, electricity import represents 92% of the total electricity needs, while in the first week of July this percentage drops to 56%. The total electricity exports amount to 773 MWh, with the highest export of 30 MWh during the second week of July. Finally, the use of electric batteries allows balancing around 128 MWh on an annual basis.

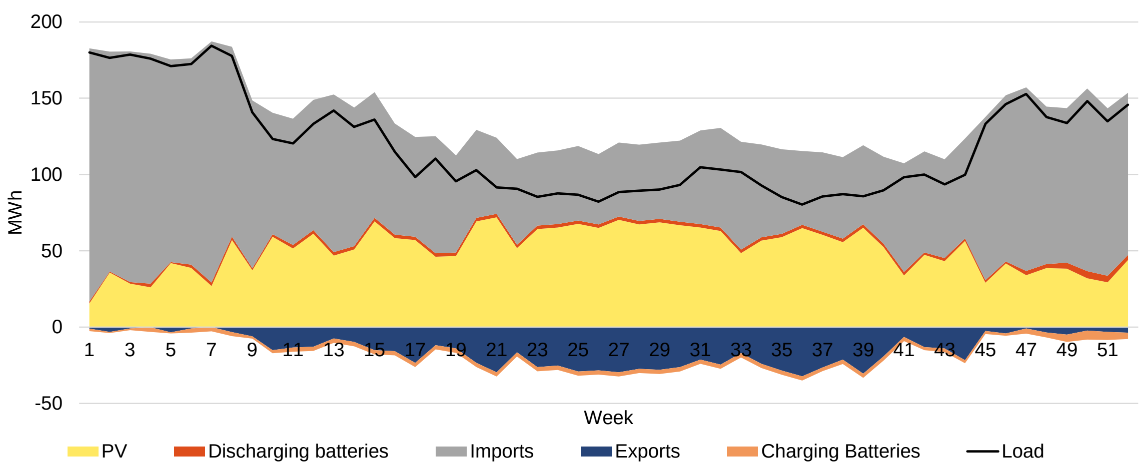

Figure 71: Annual electric supply according to the Ref-SC in the village of Berchidda in 2030

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Figure 72 and Figure 73 illustrate the hourly electricity supply profile for the village of Berchidda for the first two weeks of January and July in 2030, respectively. Both figures show how **the surplus of electricity production from PV panels can be stored in batteries to be consumed in another moment or exported to the national grid**. This effect happens more often during the summer period as the electricity production from PV is higher. During summertime, it is common that the electricity production is higher than demand leading to that. At the same time one part of the electricity is exported and another is stored in batteries. However, **this excess of electricity production can also cause curtailment of PV electricity as the electricity production cannot always be absorbed** by the load, exported, or stored.

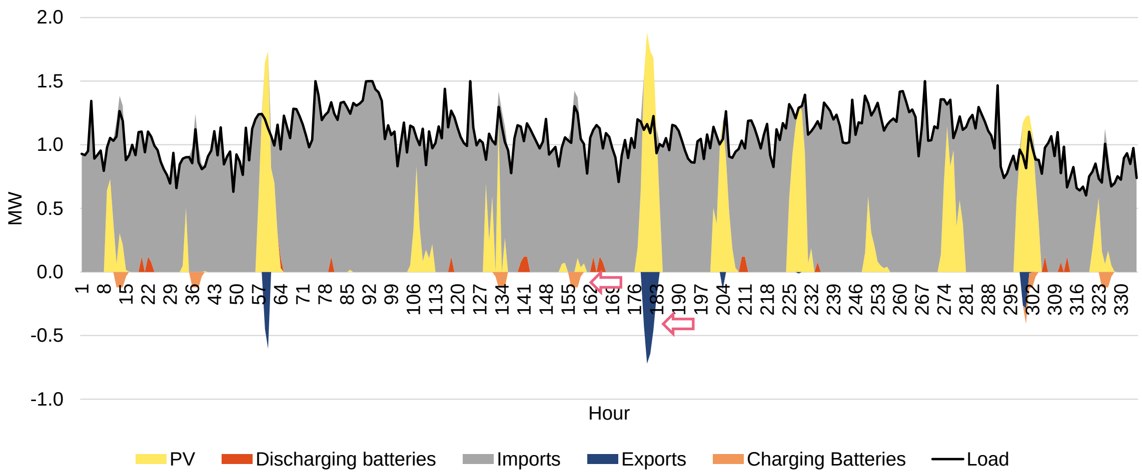

Figure 72: Hourly electricity production in the first two weeks of January according to the Ref-SC in the village of Berchidda in 2030

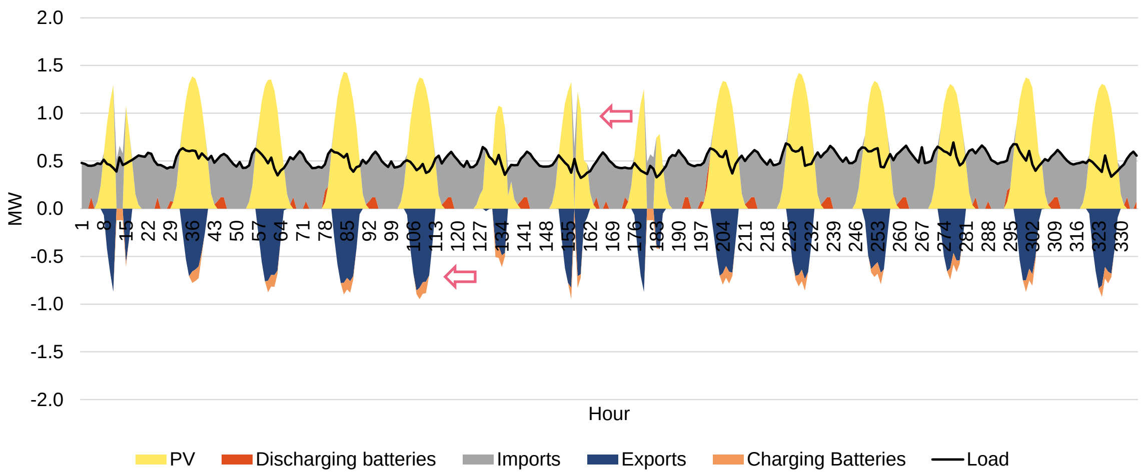

Figure 73: Hourly electricity production in the first two weeks of July according to the Ref-SC in the village of Berchidda in 2030

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HEATING SECTOR

Figure 74 shows the annual heat supply in the Ref-SC per week by heat production technologies in 2030. In the village of Berchidda, **heat is produced and consumed locally, without the possibility of heat trading with an external network outside the community**. The total heat production is estimated as 12,173 MWh (including distribution losses) on an annual basis. **Biomass boilers are the main heat source** with 5,323 MWh followed by air-source HPs to cover the space heating with 2,321 MWh, which represent 44% and 19% of the total heat supply, respectively. Although electricity consumption of HPs and electric boilers for space heating are similar, HPs generate more heat due to the COP of these technologies. Heat storage can balance 56 MWh of heat load for DHW production. **Heat storage is mainly linked to solar thermal panels**, making these resources more active during summertime, when the radiation is higher.

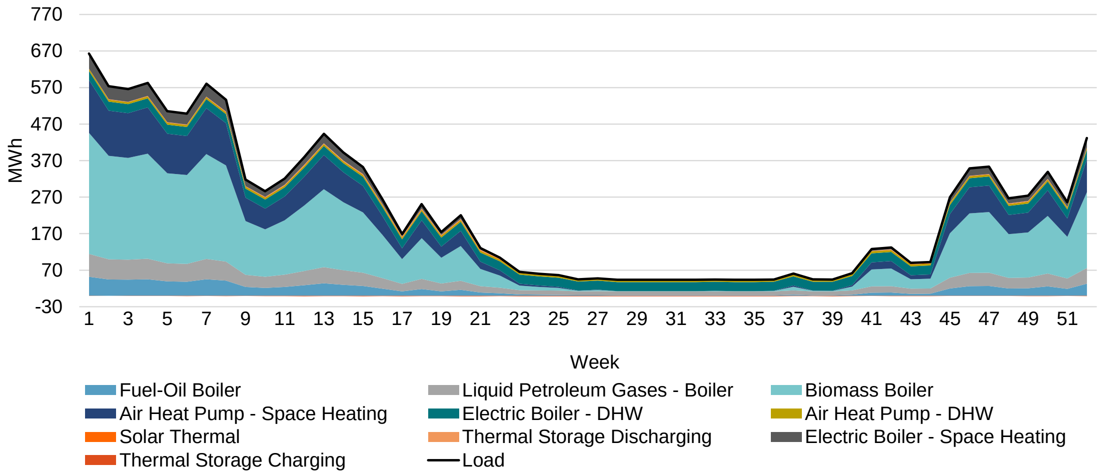

Figure 74: Annual heat production by technology according to the Ref-SC in Berchidda in 2030

Figure 75 and Figure 76 illustrate hourly heat production profiles for the first two weeks of January and July in 2030, respectively. **Thermal storage is in operation only in few hours during the winter period due to the low solar radiation**. During the summer period, heat storage is more active to store the surplus of heat generated from the solar thermal panels and shift this heat to another period. **The discharge of the heat storage takes place during the periods when the electricity prices are higher to reduce DHW fuel cost**.

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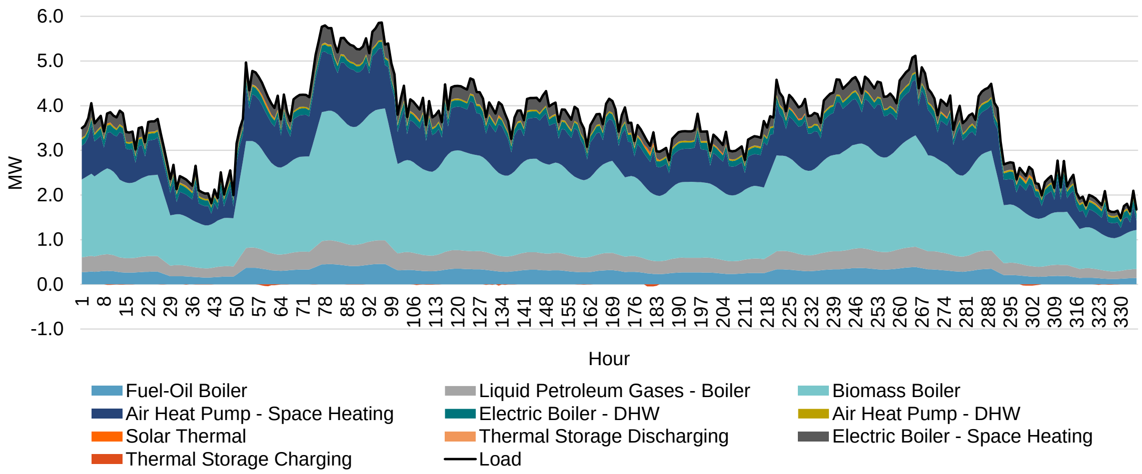

Figure 75: Hourly heat production by technologies in the first two weeks of January according to the Ref-SC in the village of Berchidda in 2030

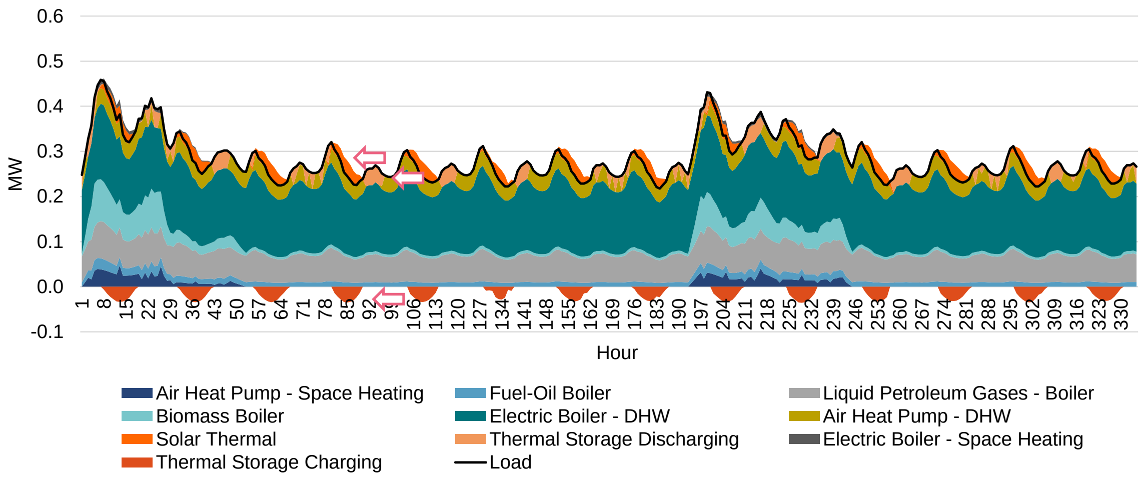

Figure 76: Hourly heat production by technology in the first two weeks according to July of the Ref-SC in the village of Berchidda in 2030

CO_2 EMMISSIONS

Figure 77 shows the direct and indirect CO_2 emission by sector of the Ref-SC scenario in the village of Berchidda. The total CO_2 emissions account for 2,474 tons of CO_2, of which 879 tons of CO_2 are indirect emissions due to the electricity consumption from the national grid, while the remaining are direct emissions from the different sectors. In the calculation of the indirect CO_2 emissions in 2030, an emission intensity of electricity production of 246 tons of CO_2 by MWh is considered based on the Italian NECP (European Commission, 2022). There is a reduction of 34% in the overall CO_2 emissions compared to the base year due to the increase of local PV production as well as the use of HPs in the service and residential sectors, in combination with the reduction of the heat demand

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due to a higher insulation, the decrease of the population and the slight reduction of the intensity of electricity production. The transport sector is the main sector in terms of emissions with overall direct CO_2 emissions of 983 tons of CO_2, 17% less compared to the base year. The residential sector is the one with the highest reduction with 526 tons of CO_2, 54% less compared to the base year.

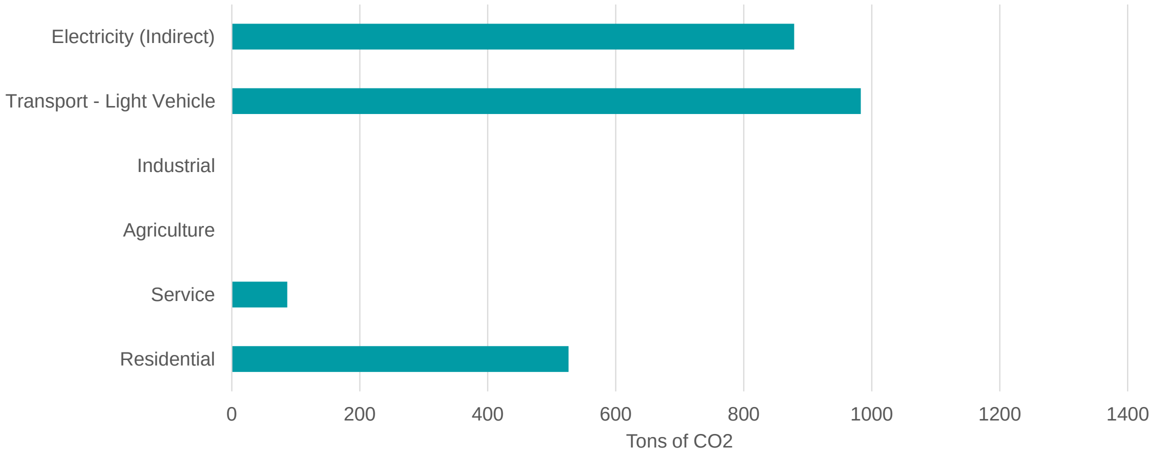

Figure 77: CO_2 emissions by sector of Ref-SC scenario in Berchidda

4.5.2. BK-SC

This scenario explores how flexible measures and local resources can support to mitigate blackout events and reduce the dependence on the national transmission grid. To assess how the system performs within this event, **a blackout is forced in the transmission line of the village of Berchidda during the most critical time**. Furthermore, **this event is combined with the identification of the minimum transmission line capacity needed**.

Residual load is used as an indicator to identify the most critical time when Berchidda is more dependent to the transmission line to the village. The residual load is defined as the load at each time minus the local electricity production from vRES, such as PV panels in this specific case.

Figure 78 shows the residual load for the village of Berchidda, the positive values are the hours when the load is higher than the electricity production from PV, implying a high dependence on the transmission line and where other flexibility measures such as electric batteries can be more active to prevent the blackout. Negative values represent the PV surplus, meaning that local electricity production from PV exceeds the load. **The highest positive value of the residual load is 1.53 MW and takes place during the 4th of January** (hour 92 of the year). At this moment, **a blackout is forced in the model avoiding electricity exports and imports** in the village of Berchidda.

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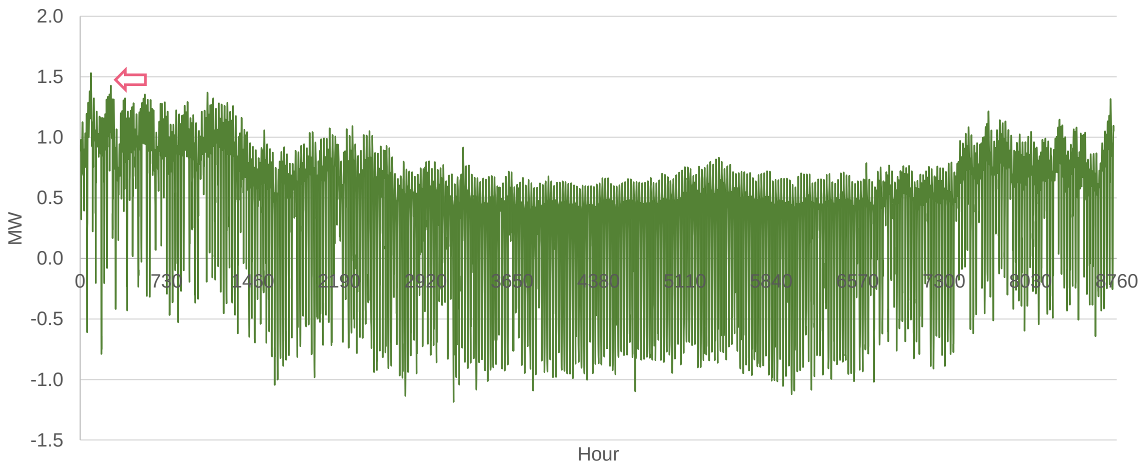

Figure 78: Residual load for the village of Berchidda

Figure 79 shows the overall local installed heat and electricity production capacities, and the electricity transmission line capacity for the BK-SC. In this scenario, PV capacity has a high increase, like in the Ref-SC, with an installed capacity of 2,110 kWp. However, **the electric batteries capacity grows up to 1 MWh**, the maximum technical capacity identified for the village of Berchidda, **to minimize the impact of the blackout**. In parallel, the different flexibility measures allow to reduce 15% the effective transmission capacity from 1.5 MW to 1.28 MW. The heating sector performs similar as for the Ref-SC, with biomass boilers being the main technology with 2.95 MW installed capacity, followed by air-source HPs for space heating with an installed heat capacity of 1.4 MW. Also, solar thermal as well as the heat storage remain similar.

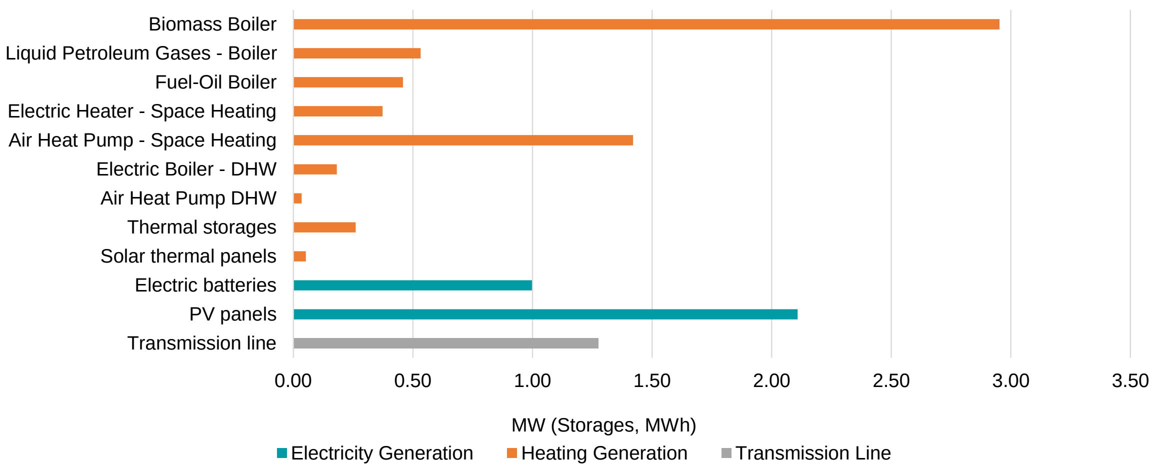

Figure 79: Local installed heat and electricity production capacities by technology and electricity transmission line capacity according to the BK-SC in the village of Berchidda in 2030

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ELECTRICITY SECTOR

Figure 80 shows the annual electricity demand in the BK-SC, as well as the impact of DSM per week in 2030. This electricity load is similar as in the Ref-SC since both scenarios must meet the load projection of the DMD-Ref demand scenario. In this context, the total annual electricity demand for the BK-SC is estimated at 6,189 MWh (including 3% of electricity distribution losses). This value is equal to the Ref-SC minus the expected energy which is not served (EENS) due to the forced blackout in the model. As in the Ref-SC, **appliances are the main electricity consumers** with 3,330 MWh followed by electric boilers used for DHW with 1,282 MWh, that represents 54% and 21% of the total electricity demand, respectively. Electricity consumption for space heating (air-source HPs and electric boilers) accounts for 1,328 MWh with the same unbalance between winter and summer periods. Nevertheless, DSM shifts around 77 MWh electricity, 12% less than in the Ref-SC as result of the higher installed battery storage capacity, which allows more flexibility in this scenario. Finally, electricity consumption of air-source HPs used for DHW remains the same with 72 MWh.

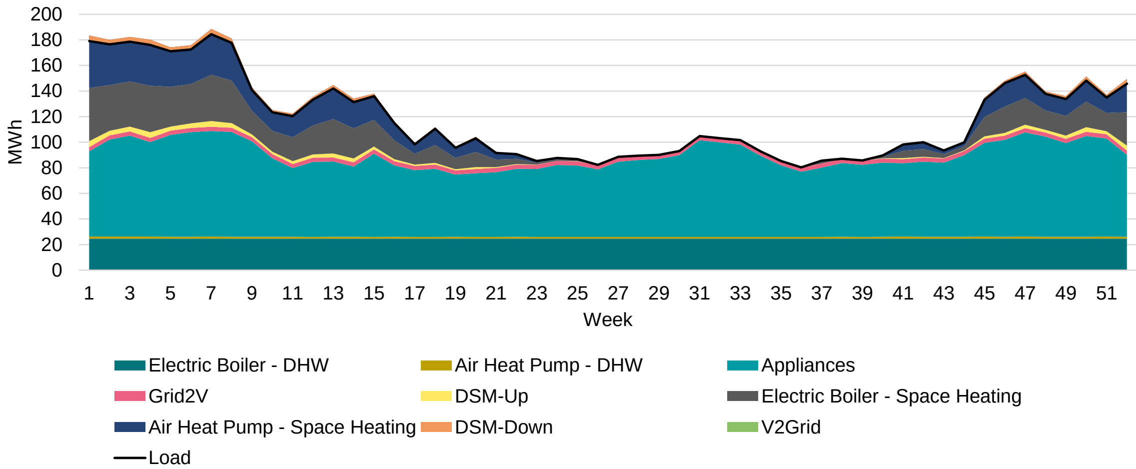

Figure 80: Annual electric demand by technology according to the BK-SC in Berchidda in 2030

Figure 81 and Figure 82 illustrate the hourly electricity demand profiles for the first two weeks of January and July in 2030, respectively. Figure 81 also shows the simulated blackout period on 4th of January (hour 92). During this period **electricity demand can be covered partly (around 0.3 MWh) with its own local sources in Berchidda. This leads to the necessity to disconnect several electric devices** from the electric network as the local production of around 0.3 MWh can cover basic services only. The specific devices to be disconnected should be selected by the village to keep running the most critical infrastructure. The limitation of the transmission line capacity to 1.28 MW makes that DSM system is more active to shift electricity load during the peak periods.

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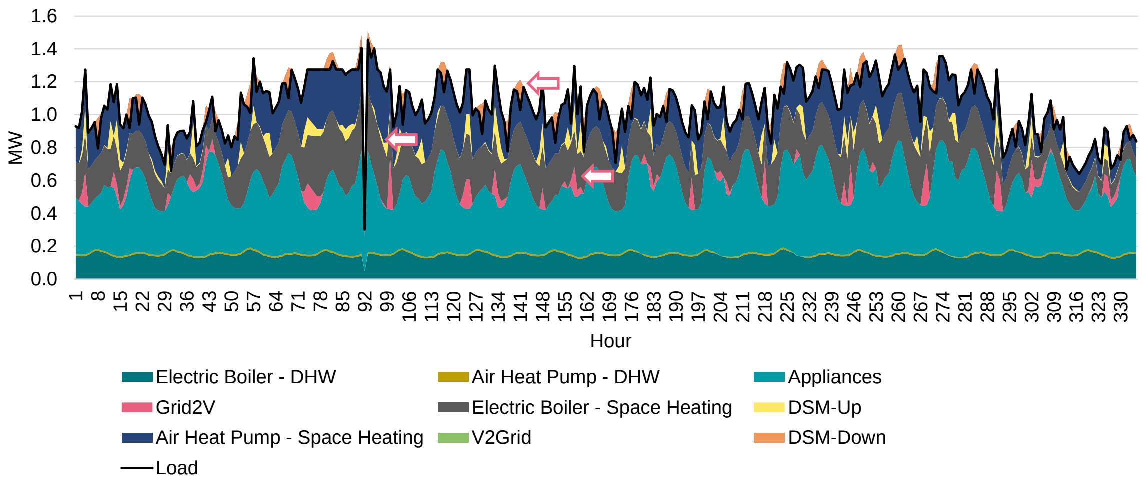

Figure 81: Hourly electricity demand in the first two weeks of January according to the BK-SC in the village of Berchidda in 2030

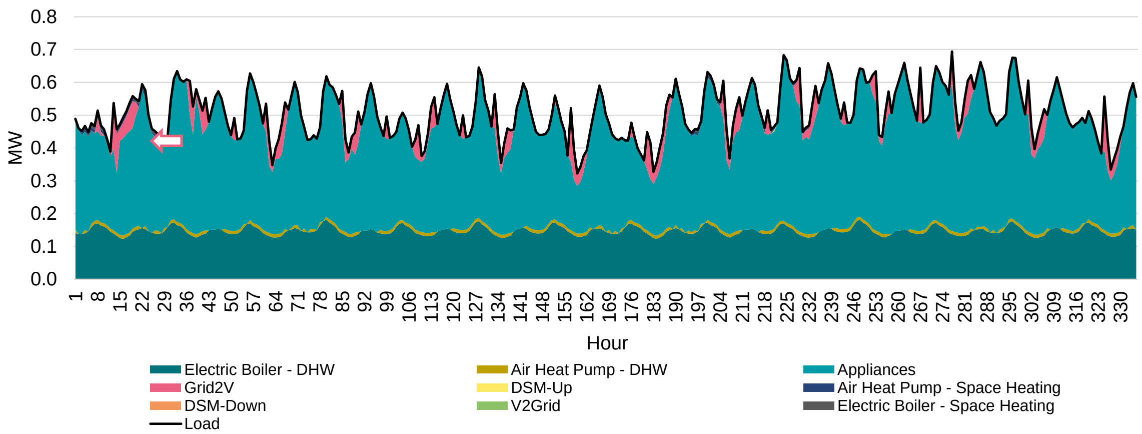

Figure 82: Hourly electricity demand in the first two weeks of July according to the BK-SC in the village of Berchidda in 2030

Figure 83 shows the annual electricity supply of the BK-SC from local sources (mainly PV), imports and exports as well as charging and discharging of batteries needed to cover the electricity demand per week in 2030. Positive values are the electricity supply components, whereas the negative ones represent the demand components such as charging of batteries or electricity export. Accordingly, the annual locally-generated electricity in Berchidda is 2,648 MWh, equivalent to 43% of the total electricity demand (including transmission losses) and it is generated with PV only. This value is **slightly higher than for the Ref-SC as result of the higher installed battery storage capacity, reducing the PV curtailment**. Due to the reduction of the transmission line capacity, annual electricity imports and exports are also slightly reduced compared to Ref-SC accounting 4,320 MWh and 711 MWh respectively. Finally, **the use of batteries allows a higher balance** with around 243 MWh on annual basis, almost double compared to the Ref-SC.

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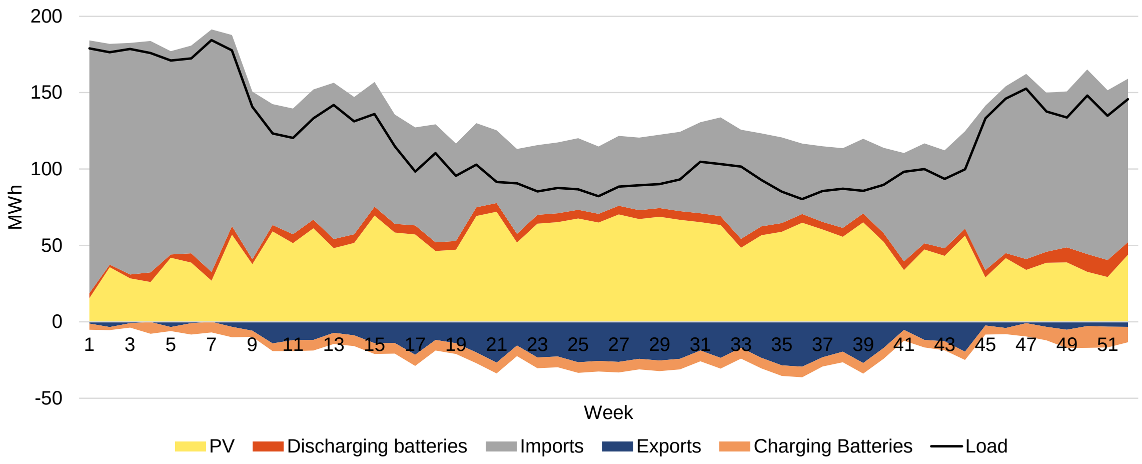

Figure 83: Annual electric supply according to the BK-SC in the village of Berchidda in 2030

Figure 84 and Figure 85 illustrate hourly electricity supply profiles for the first two weeks of January and July in 2030, respectively . Figure 84 also shows the simulated blackout period on 4th of January (hour 92). During this period only around 0.3 MWh electricity demand can be covered with the local sources. This partial demand is covered mainly by electric batteries of the village. **Despite the electric storage capacity is 1MWh, the charging and discharging periods of 3.3 hours limits the power capacity to 0.3 MW**. Both figures show how the generated electricity surplus from PV can be stored in batteries and can be used later or exported to the national grid, which would increase the revenue for the community. The batteries are also charged by importing electricity moments when electricity prices are low. This increases the trading with the national grid. Moreover, **price-based operation (controlled charging) of batteries results in electricity being effectively traded with the national grid**. During the summer period, PV curtailments are also reduced because of the higher battery capacity.

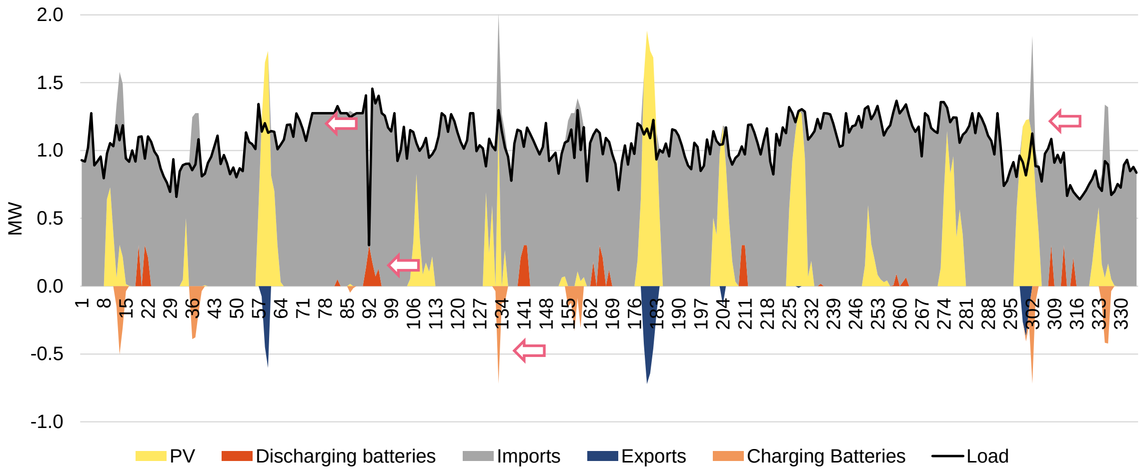

Figure 84: Hourly electricity production in the first two weeks of January according to the BK-SC in the village of Berchidda in 2030

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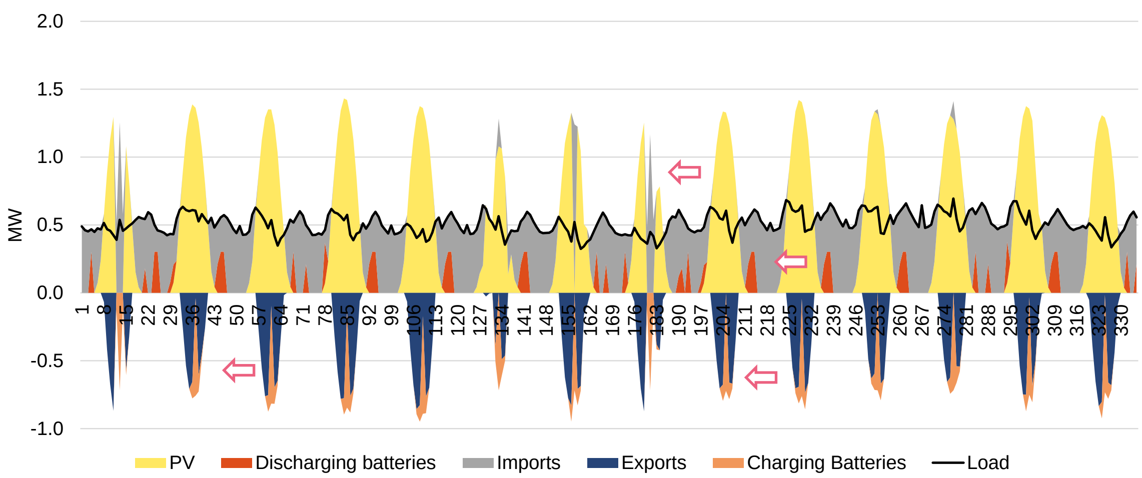

Figure 85: Hourly electricity production in the first two weeks of July for the BK-SC in Berchidda in 2030

HEATING SECTOR

Figure 86 shows the annual heat supply in the BK-SC per week by different heat production technologies in 2030. As for the Ref-SC, the heat is produced and consumed locally in the village of Berchidda, not being possible to trade heat with an external network outside the community. The heating sector in the BK-SC performs as in the Ref-SC, as there are not fundamental changes. In this sense, the heat production is estimated in 12,178 MWh (including distribution losses) on annual basis. Biomass boilers are the main heat source with 5,323 MWh followed by air-source HPs to cover the space heating with 2,329 MWh, representing 44% and 19% of the total heat supply, respectively. Despite the electricity consumption of HPs and electric boilers for space heating is similar, HPs generate more heat due to the COP of these technologies. Heat storage can balance 57 MWh of heat load for DHW production. Heat storage is mainly linked to solar thermal panels; thus, these resources are more active during summer periods when the solar radiation is higher.

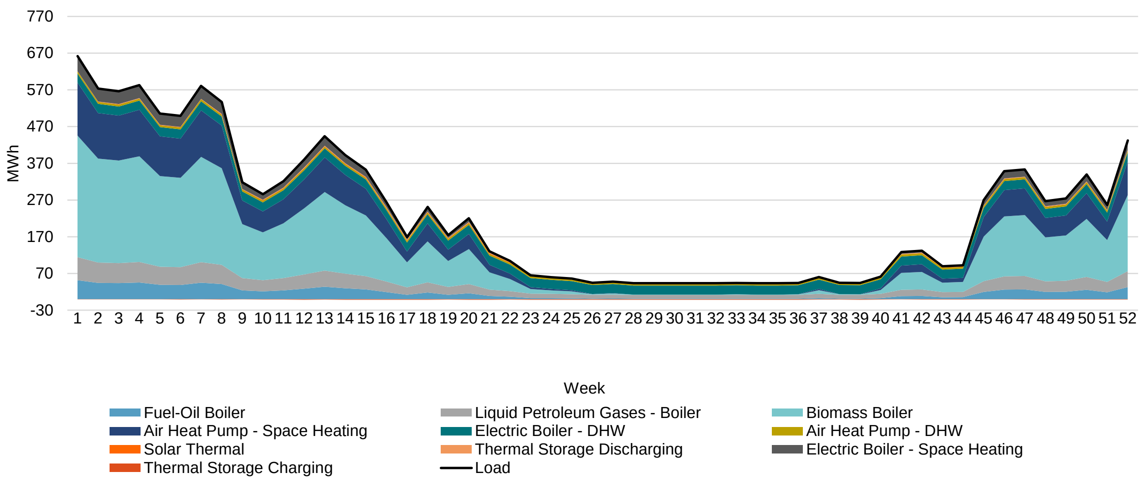

Figure 86: Annual heat production by technology for the BK-SC in Berchidda in 2030

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Figure 87 and Figure 88 illustrate hourly heat production profiles for the first two weeks of January and July in 2030, respectively. Figure 87 shows the **loss of heat production due to the blackout event that affects the electric heating system**, i.e., air-source HPs and electric boilers. In addition, a slight modification can be observed due to the impact of the DSM and electric storage. As in the Ref-SC, thermal storage -connected to solar thermal systems- is in operation for few hours only during the winter period. It can be more active during the summer periods due to surplus heat generated from the solar thermal panels. The discharging of the heat storage takes place during the periods when the electricity prices are higher, to reduce electricity consumption for DHW.

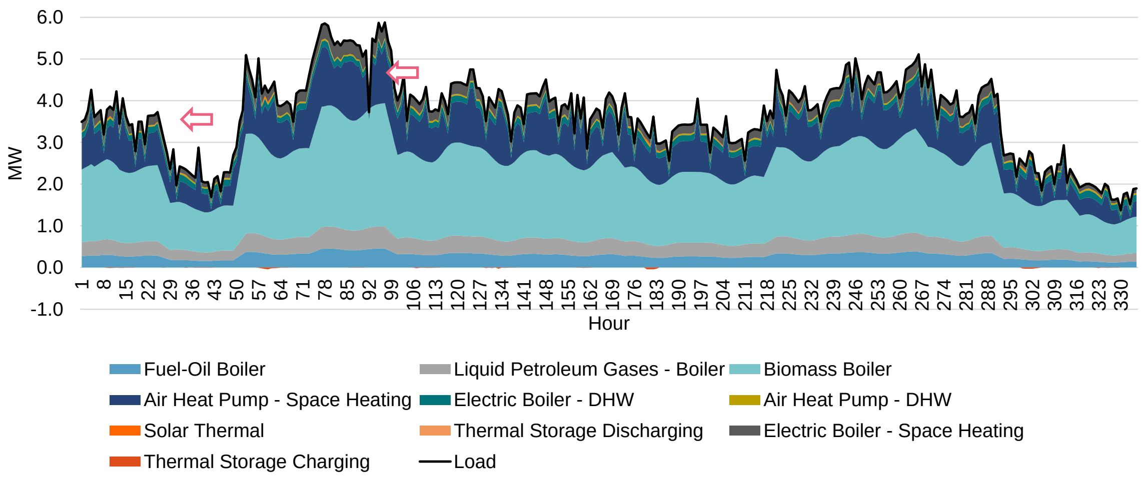

Figure 87: Hourly heat production in the first two weeks of January according to the BK-SC in the village of Berchidda in 2030

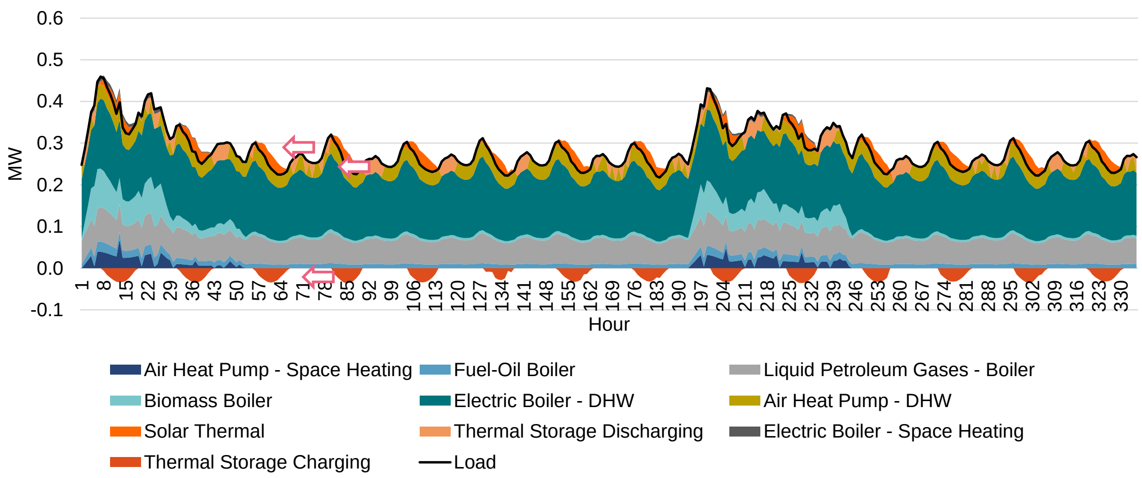

Figure 88: Hourly heat production in the first two weeks of July according to the BK-SC in the village of Berchidda in 2030

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CO_2 EMMISSIONS

Figure 89 shows the direct and indirect CO_2 emission by sector of the BK-SC scenario in the village of Berchidda. This scenario performs in a similar way as the Ref-SC, as no fundamental differences exist between both scenarios. In this context, the total CO_2 emissions account for 2,482 tons of CO_2, of which 886 tons of CO_2 are indirect emissions due to the electricity consumption from the national grid, and the remaining are direct emissions from the different sectors. There is only a small increase in the indirect CO_2 emissions from the national grid due to the need to mitigate possible blackouts. Therefore, as in the Ref-SC, there is a reduction of 34% in the overall CO_2 emissions compared with the base year. The transport sector is the main emitting sector with overall direct CO_2 emissions of 983 tons of CO_2, 17% less compared to the base year. Residential sector is the one with the highest reduction with 526 tons of CO_2, 54% less compared to the base year In the calculation of the indirect CO_2 emissions in 2030, an emission intensity of electricity production of 246 tons of CO_2 by MWh is considered based on the Italian NECP (European Commission, 2022).

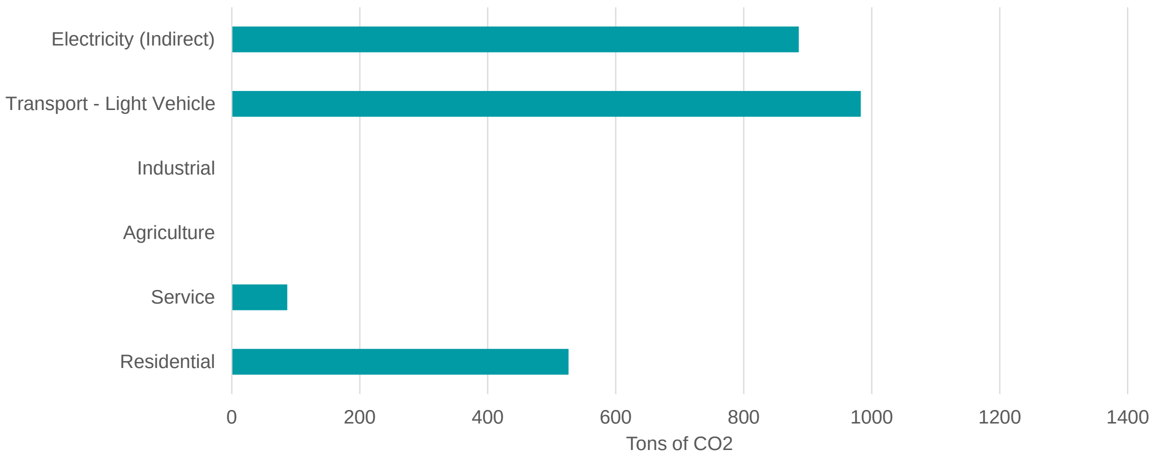

Figure 89: CO_2 emissions by sector of BK-SC scenario in the village of Berchidda

4.5.3. ELC-SC

This scenario explores the full electrification of the village of Berchidda. Figure 90 shows the overall local heat and electricity production, and the transmission line capacity according to the ELC-SC. In the electric sector, **the installed PV has the same expansion as in the Ref-SC and the BK-SC**, with an installed capacity of 2,110 kWp. **The capacity of electric batteries grows up to the maximum technical capacity of 1 MWh**. **The increase in the electric demand produces a higher dependence on the national grid**, increasing the effective needed transmission capacity 40% from 1.5 MW to 2.1 MW. In the heating sector, **air-source HPs are the main available technology** with a total capacity of 6.03 MW for space heating and DHW. The capacity of the solar thermal panels remains the same as in the Ref-SC and the BK-SC. However, **the thermal storage capacity grows around six times** up to 1.5 MWh to take advantages of the fluctuations of the electricity prices.

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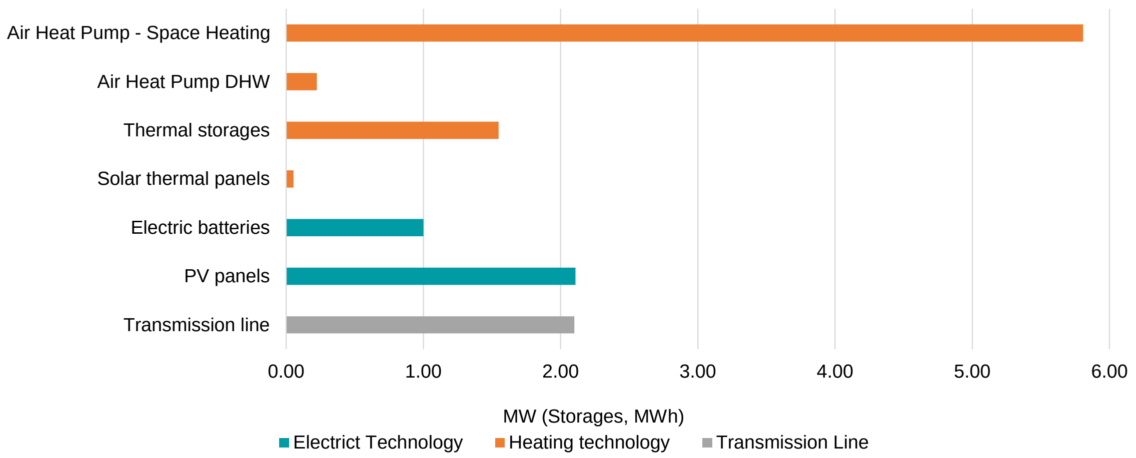

Figure 90: Local energy production and transmission line capacities for the ELC-SC in Berchidda in 2030

ELECTRICITY SECTOR

Figure 91 shows the annual electricity demand in the ELC-SC as well as the impact of DSM per week in 2030. The total yearly electricity demand is estimated as 9,349 MWh (including 3% of electricity distribution losses), 51% higher compared to the Ref-SC and the BK-SC. Electric appliances are the main electricity consumers with 3,739 MWh. This **increase is mainly due to the electrification of the stoves, followed by air-source HPs for space heating** with 2,828 MWh, corresponding to a 40% and 30% of the electricity demand, respectively. Electricity consumption for space heating can represent up to 59% in wintertime as in the first week of the year. Despite the electricity demand for EVs is 1,729 MWh, the real absorbed electricity in this scenario is 2,251 MWh, as **V2G technology is in place enabling to feed electricity back to the grid from electric batteries of EVs**. DSM can shift around 191 MWh of the space heating demand, which is about 120% more than in the Ref-SC, since the highest air-source HP capacity of this technology generates a higher potential for this flexibility measure. Finally, to cover the heating demand for DHW by HPs, the electricity consumption experiences around a sevenfold increase compared to the Ref-SC, up to 521 MWh.

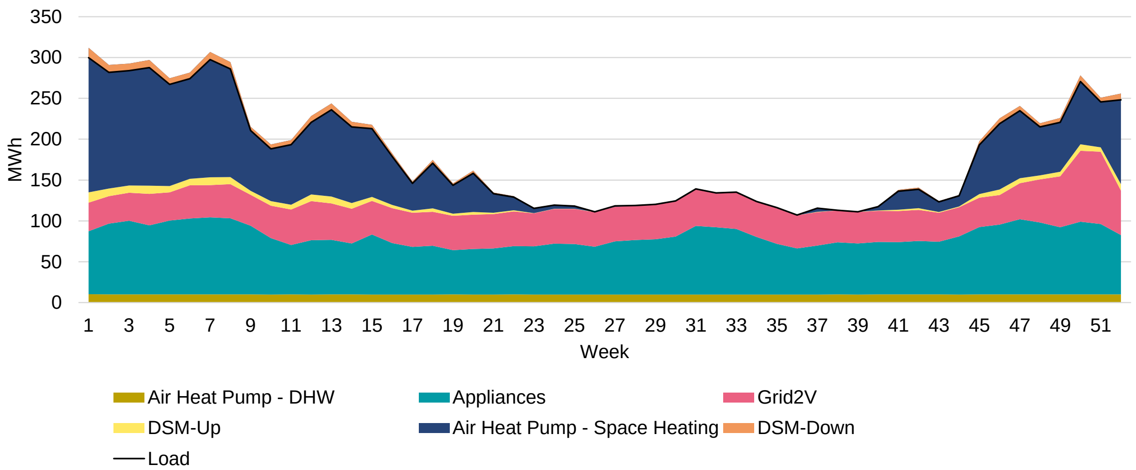

Figure 91: Annual electric demand by technology according to the ELC-SC in Berchidda in 2030

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Figure 92 and Figure 93 illustrate hourly electricity demand profiles for the first two weeks of January and July in 2030, respectively. **DSM allows to reduce the electricity peak during the winter period** due to the limitation of the transmission line capacity of 2.1 MW by switching the heat load of the air-source HPs for space heating. In both figures, **the charging of EVs affects the overall electricity demand profile, producing a saw-tooth effect** due to the higher number of EVs connected to the grid. There is a **possibility to trade electricity with the national grid, charging the batteries in EVs at lower electricity prices** and feeding the stored electricity back again to the grid when electricity prices are higher. This effect is especially higher during the summer period representing at certain times around 90% of the electricity demand.

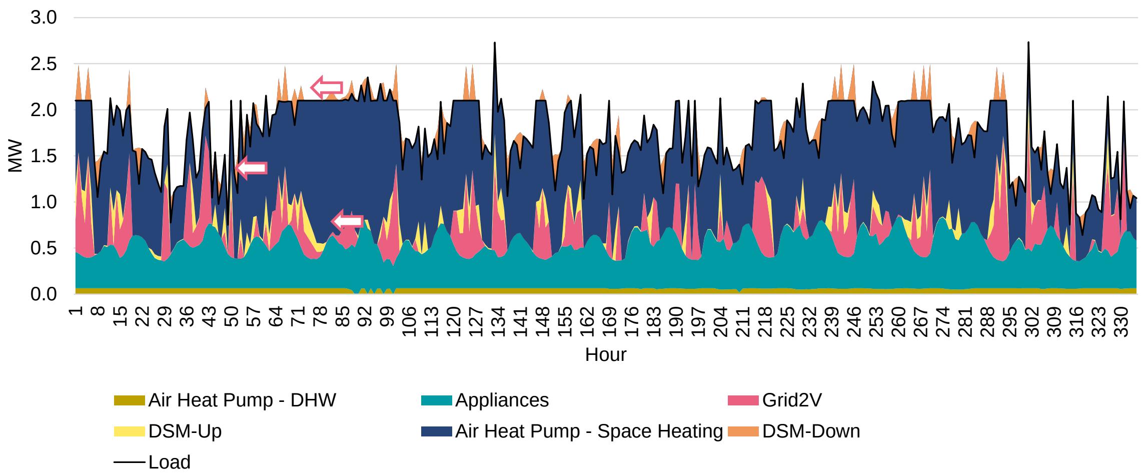

Figure 92: Hourly electricity demand in the first two weeks of January according to the ELC-SC in the village of Berchidda in 2030

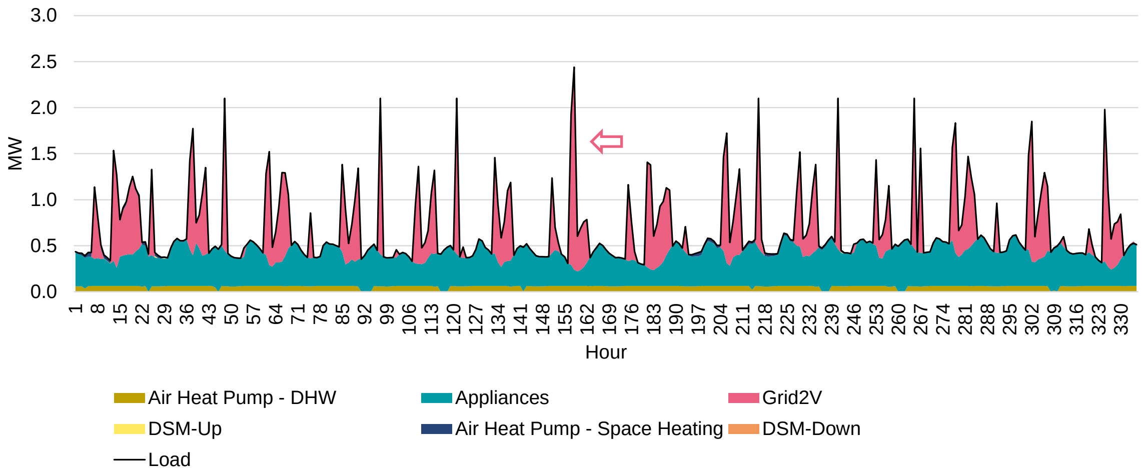

Figure 93: Hourly electricity demand in the first two weeks of July of the ELC-SC in the village of Berchidda in 2030

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Figure 94 shows the annual electricity supply in the ELC-SC from local sources (mainly PV), imports and exports as well as charging and discharging of batteries needed to cover the electricity supply per week in 2030. Positive values are electricity supply components, whereas the negative ones represent the demand components, such as charging of batteries or electricity export. The annual locally-generated electricity accounts for 2,683 MWh, equivalent to 29% of the total electricity demand (including transmission losses) and it is generated by PV only. This value is slightly higher than in the Ref-SC because of **the higher capacity of the transmission line capacity, which allows a higher trading with the national grid by also reducing the PV curtailment**. The annual electricity imports increase up to 7,128 MWh, 64% more compared to the Ref-SC, with a higher dependence to the national grid. During the first week of January, the electricity import represents 95% of the total electricity and 60% in the first week of July. The total electricity exports are 766 MWh, as occurs in the Ref-SC. Finally, the use of fix electric batteries allows to balance 312 MWh on an annual basis, whereas the use of batteries of the EVs contributes with 389 MWh. This means **over five times more batteries are installed in the system compared to the Ref-SC**.

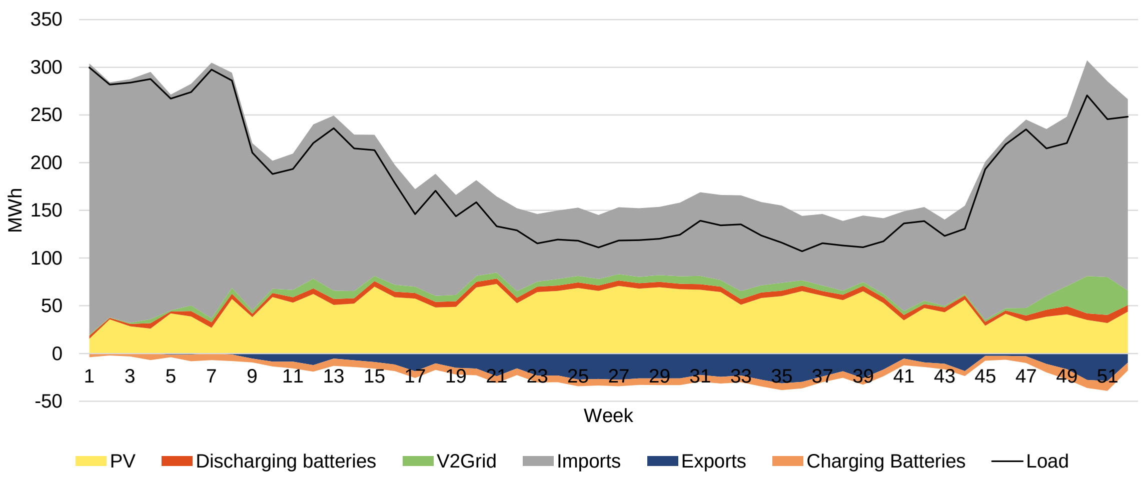

Figure 94: Annual electricity supply according to the ELC-SC in the village of Berchidda in 2030

Figure 95 and Figure 96 illustrate hourly electricity supply profiles for the first two weeks of January and July in 2030, respectively. Both figures show how **the electricity surplus generated from PV can be stored** in electric batteries (fixed ones or installed in the EVs) **to be used later or exported to the national grid, which would increase the revenue for the community**. Furthermore, the batteries are also charged by imported electricity during the times when electricity prices are lower, thus increasing the trading with the national energy grid.

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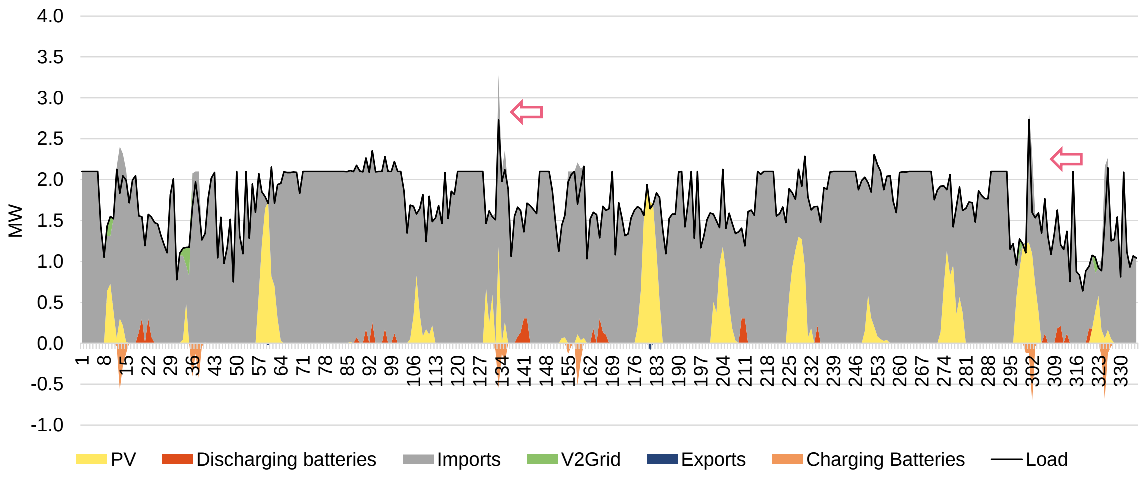

Figure 95: Hourly electricity production in the first two weeks of January according to the ELC-SC in the village of Berchidda in 2030

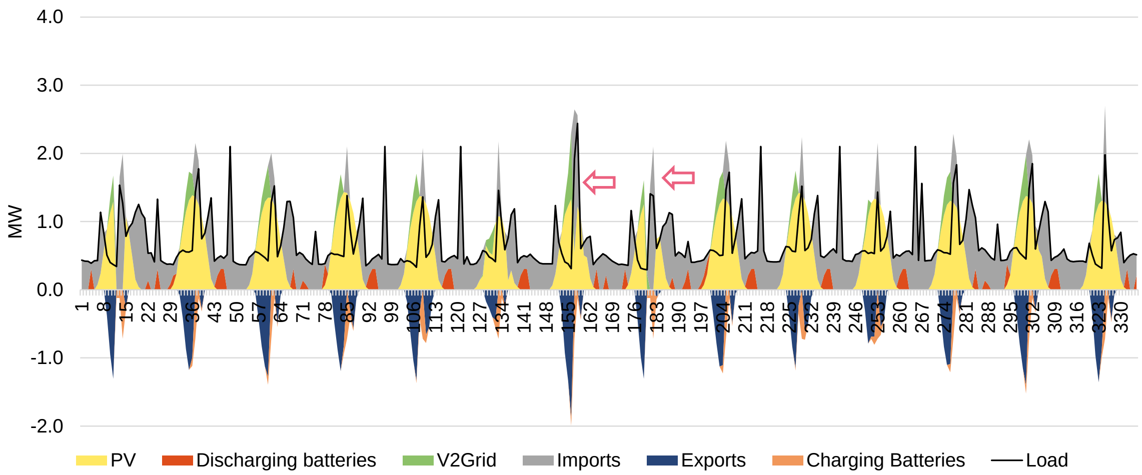

Figure 96: Hourly electricity production in the first two weeks of July according to the ELC-SC in the village of Berchidda in 2030

HEATING SECTOR

Figure 97 shows the annual heat supply in the ELC-SC per week by different heat production technologies in 2030. In the village of Berchidda, the heat is produced and consumed locally. The total heat production is estimated in 11,816 MWh (including distribution losses) on an annual basis. **This thermal demand is almost completely satisfied by the air-source HPs**, and only 70 MWh are produced from solar thermal panels. The higher thermal storage capacity allows to balance 114 MWh of heat load for DHW production.

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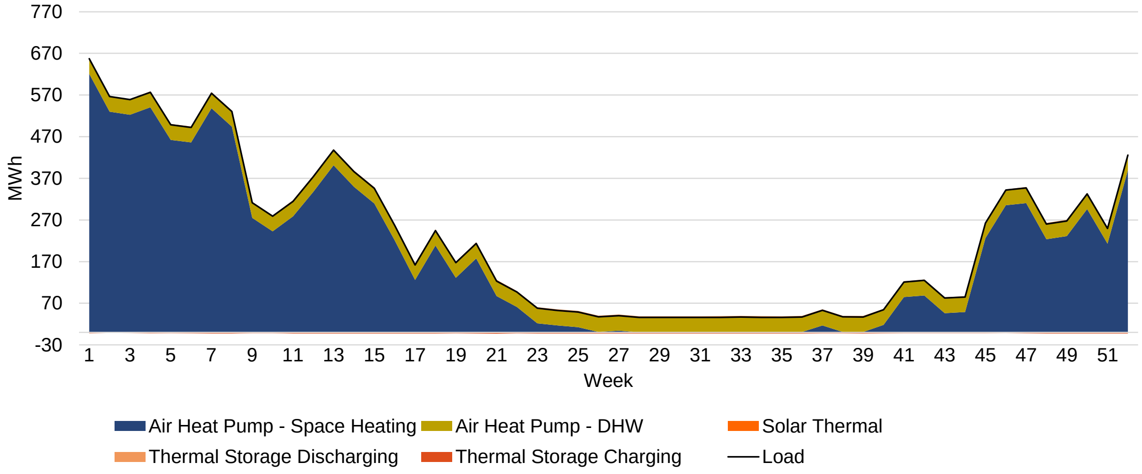

Figure 97: Annual heat production by technology according to the ELC-SC in Berchidda in 2030

Figure 98 and Figure 99 illustrate representative hourly heat production profiles for the first two weeks of January and July in 2030, respectively. The thermal storage is in operation only in few hours during the winter period due the low solar radiation. As occurs in other scenarios, here it can be also more active during the summer periods due to the surplus heat generated from the solar thermal panels. Moreover, **during the summer period thermal storage systems are also charged for DHW with the heat generated from the air-source HPs, when the electricity prices are lower**, and discharged, when electricity prices are higher.

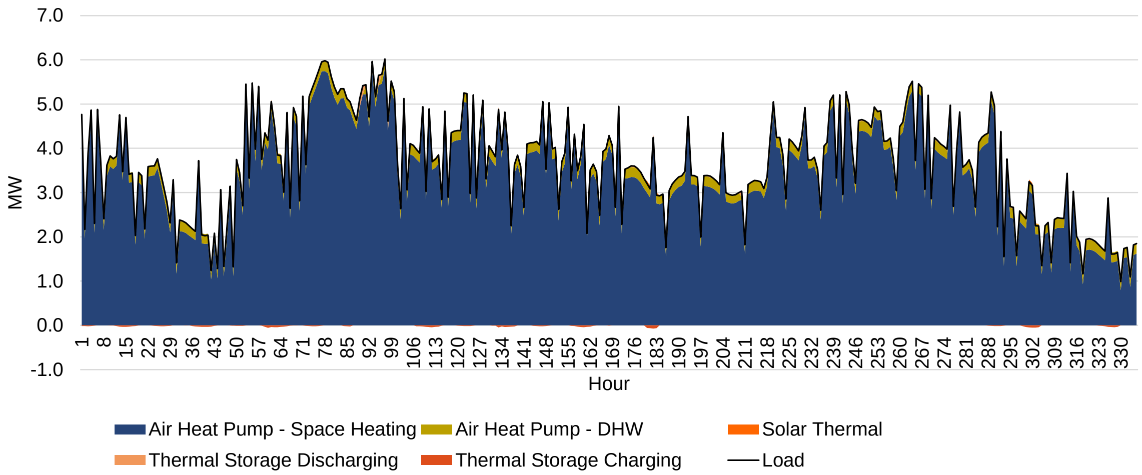

Figure 98: Hourly heat production in the first two weeks of January according to the ELC-SC in the village of Berchidda in 2030

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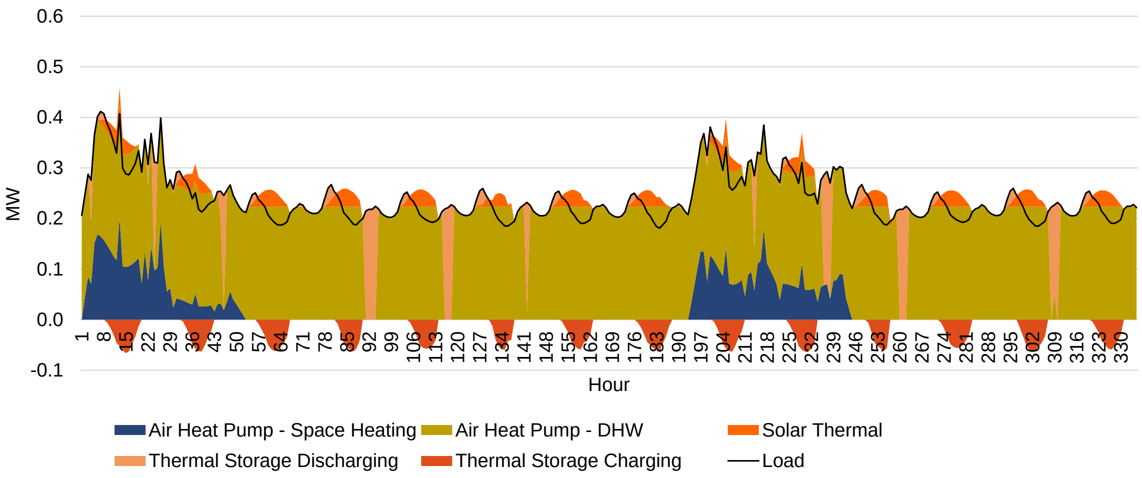

Figure 99: Hourly heat production in the first two weeks of July according to the ELC-SC in the village of Berchidda in 2030

CO_2 EMMISSIONS

Figure 100 shows the CO_2 emission by sector of the ELC-SC scenario in the village of Berchidda. In this scenario, there is a full decarbonization of the direct CO_2 emissions. Therefore, the total CO_2 emissions account for 1,562 tons of CO_2 of indirect emissions due to the electricity consumption from the national grid, 59% less compared to the base year. These indirect CO_2 emissions are due to the full electrification of the transport sector as well as to the use of HPs to cover the heat demand.

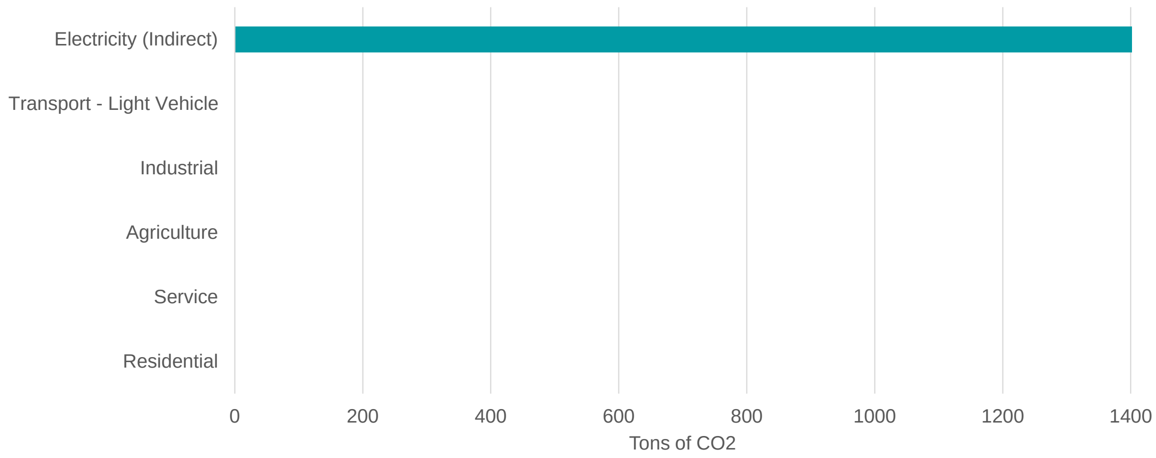

Figure 100: CO_2 emissions by sector of ELC-SC scenario in the village of Berchidda

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4.6. Comparison of scenarios for Berchidda

4.6.1. Electric sector

Figure 101 shows the comparison of the electric capacity of the local electric production sources and the transmission line of the scenarios and the base year in the village of Berchidda. For all the assessed scenarios, the PV capacity has a high increase with an installed capacity of 2,110 kWp compared to 2017, which is the maximum technical potential identified for Berchidda. Despite there is a need of 0.4 MWh of electric batteries capacity to balance the electric system already in the Ref-SC scenario, the capacity increases both in the BK-SC scenario, to mitigate the impact of black-out in the village, and in the ELC-SC scenario, with the fully electrification of the village, reaching the maximum of 1 MWh of the technical capacity. In addition, the high increase of the use of batteries together with the flexibility measures allows reducing the transmission capacity effectively needed in 15%, from 1.5 MW to 1.28 MW, in the BK-SC scenario. However, the high increase in the electric demand in the ELC-SC scenario produces a higher dependence on the national grid, increasing the transmission capacity effectively needed by 40%, from 1.5 MW to 2.1 MW.

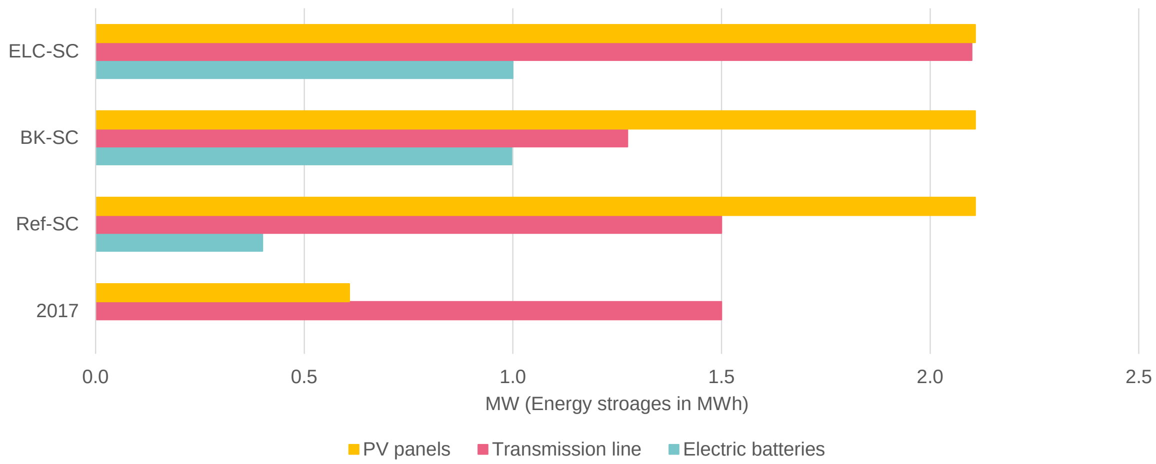

Figure 101: Comparison of the electric capacity of the local electric production sources and the transmission line of the scenarios and base year in the village of Berchidda

Figure 102 shows the comparison of the electricity demand, production, imports and exports of the scenarios and the base year in the village of Berchidda. For all the assessed scenarios, there is an increase of the electricity demand compared to the base year due to the higher electrification of the heating sector as well as the use EVs in 2030. In parallel, the higher PV capacity produces a rise of the local electricity production.

The Ref-SC and the BK-SC scenarios perform in a similar way in terms of electricity demand, local production, imports, and exports. The electricity demand in the Ref-SC scenario is estimated at 6,190 MWh, while that in the BK-SC scenario is estimated at 6,189 MWh, which is the demand in Ref-SC scenario minus the expected energy which is not served (EENS) due to the forced black-out.

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Both are practically the same, accounting for around 2,642 MWh, or 43% of the total electricity demand, although the BK-SC scenario has a local electricity production than Ref-SC scenario because of a higher installed battery storage capacity to reduce the PV curtailment. In the BK-SC scenario, the reduction of the transmission line capacity causes a slight decrease in the electricity imports and exports compared to the Ref-SC scenario.

The greatest differences occur in the ELC-SC. It accounts for an estimated electricity demand of 9,349 MWh, 51% higher compared to the Ref-SC and the BK-SC scenarios. The annual electricity imports increase up to 7,128 MWh, 64% more compared to the Ref-SC scenario, with a higher dependence from the national grid. In all the scenarios, during the summertime there is a surplus of electricity production that cannot be absorbed by the system, producing curtailment of PV electricity. This negative effect is reduced in the BK-SC and the ELC-SC scenarios due to the higher installed battery storage that allows balancing higher amounts of electricity.

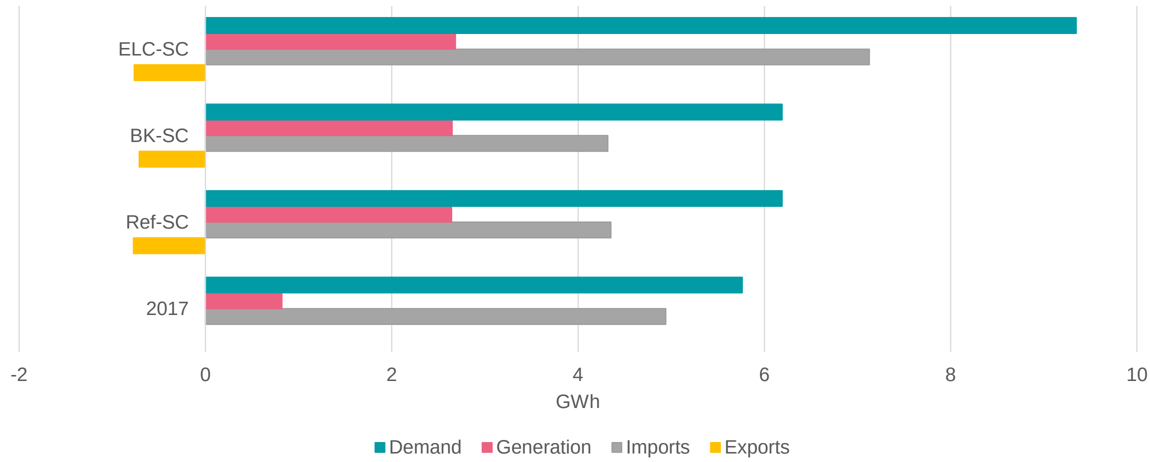

Figure 102: Comparison of the electricity demand, production, import and export of the scenarios and base year in the village of Berchidda

4.6.2. Heating sector

Figure 104 shows the comparison of the heating capacity by technology of the scenarios and the base year in the village of Berchidda. The Ref-SC and the BK-SC scenario perform in the say ways as no fundamental changes take place between both scenarios under the heating sector. Biomass boilers constitute the main technology with 2.95 MW, followed by air-source HPs for space heating with an installed heat capacity of 1.4 MW. Solar thermal panels as well as thermal storage that is used to balance its production with the consumption remain similar as in 2017. It is in the ELC-SC scenario where the most relevant changes take place. Under this scenario, air-source HPs are the main available technology with a total capacity of 6.03 MW for space heating and DHW. The capacity of the solar thermal panels remains the same as in the Ref-SC and the BK-SC scenarios, however the thermal storage capacity grows up to 1.5 MWh to take advantage of the fluctuations of the electricity prices.

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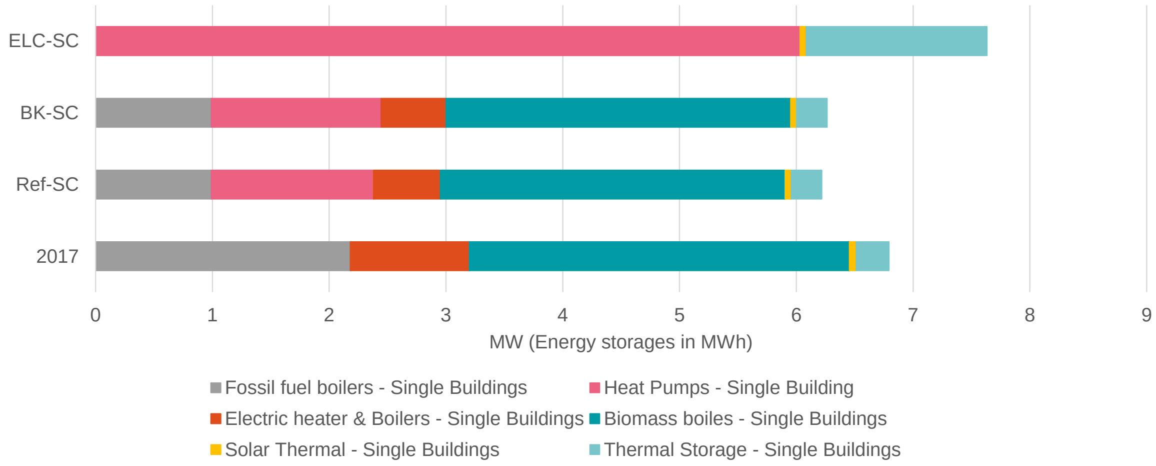

Figure 103: Comparison of the heating capacity by technology of the scenarios and base year in Berchidda

Figure 104 shows the comparison of the heat production by technology of the scenarios and the base year in the village of Berchidda. For all the assessed scenarios, there is an overall decrease of heat demand due to the improvement of the insulation of the buildings as well as the reduction of the population in 2030. In parallel, the heat generated from fossil fuels is declined, being the ELC-SC scenario where they are fully phased-out. The heating sector in the BK-SC scenario and the Ref-SC scenario perform equally. In this sense, heat production is estimated at 12,178 MWh (including distribution losses) on annual basis. Biomass boilers are the main heat source with 5,323 MWh, followed by air-source HP with 2,329 MWh to cover the space heating, representing 44% and 19% of the total heat supply. Heat storage can balance 57 MWh of the heat load for DHW production, and they are mainly linked to solar thermal panels. In the ELC-SC scenario, total heat production is estimated at 11,816 MWh (including distribution losses) on an annual basis. This demand is mainly satisfied by the air-source HPs, and only 70 MWh are produced from solar thermal panels. The higher thermal storage capacity allows balancing 114 MWh of the heat load for DHW production.

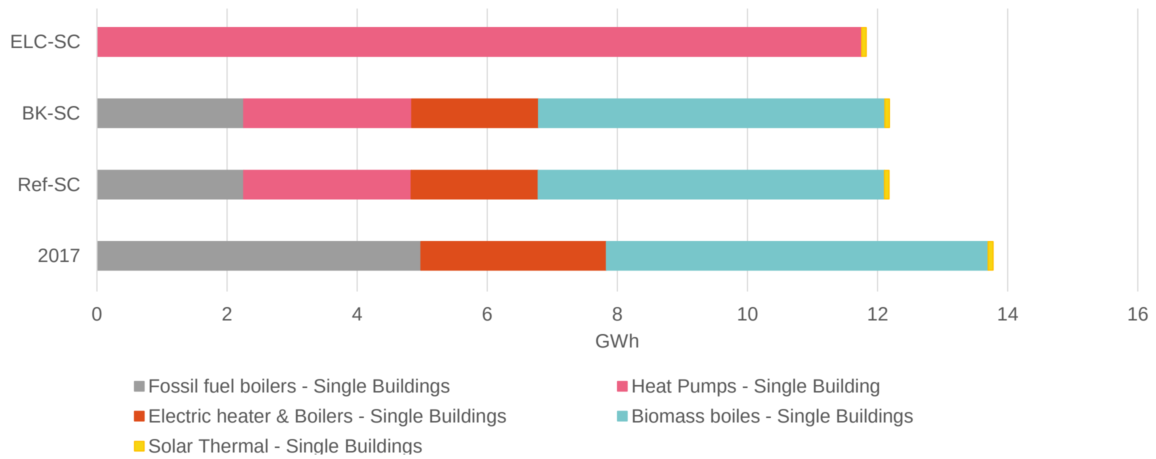

Figure 104: Comparison of the heat production by technology of the scenarios and base year in Berchidda

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4.6.3. Transport sector

Figure 105 presents the comparison of the energy consumption of the scenarios and the base year in the village of Berchidda. There is a reduction of the fuel consumption for all the assessed scenarios compared to the base year. This is due to two main aspects: the reduction of the population that implies the decrease of the use trips, and the switch from ICE vehicles to EVs with a higher efficiency. The Ref-SC and the BK-SC scenarios perform equally with an overall energy consumption of 3.89 GWh, around 14% less compared to the base year. It is in the ELC-SC scenario when the highest energy reductions take place due to the massive inclusion of EVs, accounting for 1.73 GWh; a 62% reduction compared to base year.

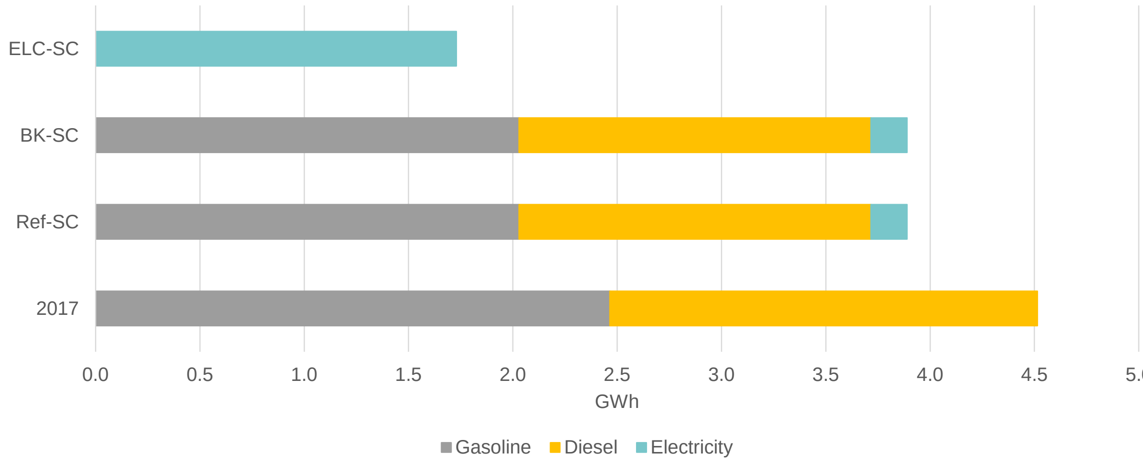

Figure 105: Comparison of the energy consumption of the scenarios and base year in Berchidda

4.6.4. Decarbonization

Figure 106 shows the comparison of the CO_2 emissions by sector of the scenarios and the base year in the village of Berchidda. In all the assessed scenarios there is a clear reduction of the overall CO_2 emissions compared to the base year. The Ref-SC and the BK-SC perform similarly with around 2,474 tons of CO_2; 34% less compared to 2017. The highest reduction takes place in the residential and service sectors due to the replacement of fossil boilers by HPs together with a slight reduction due to the inclusion of EVs. In the ELC-SC scenario there are no direct CO_2 emissions anymore because of the full electrification of the village of Berchidda. However, this scenario has the highest indirect CO_2 emissions due to the electricity imports, accounting for 1,562 tons of CO_2. This represents a reduction of 59% compared to 2017. The CO_2 emissions by MWh of the national grid are slightly reduced from the base year to the estimations in 2030, being 248 kg of CO_2/MWh and 246 kg of CO_2/MWh, respectively.

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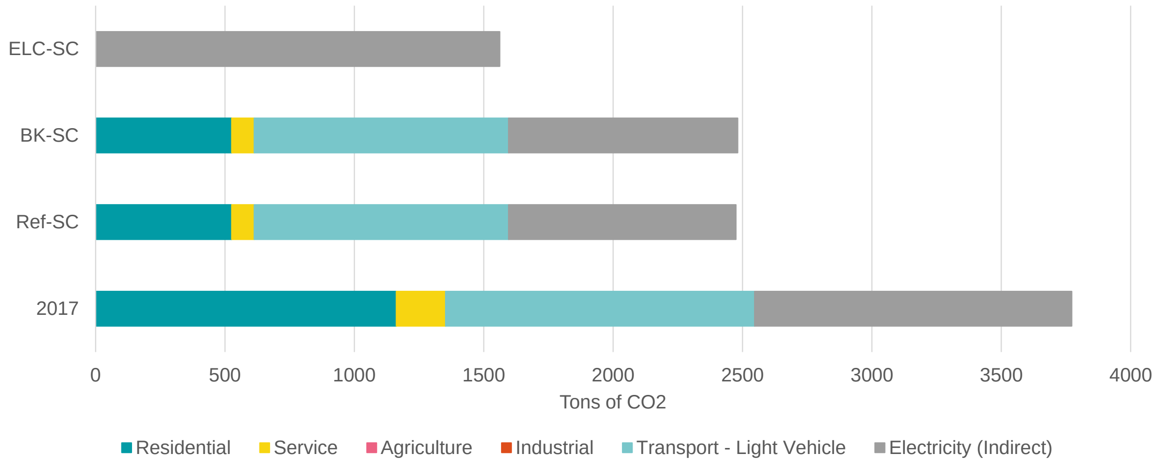

Figure 106: Comparison of the CO_2 emissions by sector of the scenarios and base year in Berchidda

4.7. Conclusions

Three scenarios are investigated under the LocalRES project for the village of Berchidda: Reference Scenario (Ref-SC), Blackout Scenario (BK-SC) and 100% Electrification Scenario (ELC-SC). The goal of these scenarios is to define in the long-term perspective (2030) different possibilities about how a hypothetical energy community constituting the whole village can perform and can support decarbonization of the municipal area.

The overall conclusion is that **flexibility measures such as DSM, smart charging of EVs and use of energy storage (electric and thermal) can support the electrification of the energy community and reduce the dependence on the national grid in the village of Berchidda**.

In general, the electrification of the heating and transport sector produces an increase of the PV capacity as well as the use batteries in the village of Berchidda. However, there is mismatch between local production and consumption, as the PV panels have the higher electricity production in summer, but the higher electricity demand is occurring in winter due to the use of HPs and electric boilers for space heating. In addition, during the summer period it could occur that **the electricity surplus generated from PV could not be absorbed, therefore it is either curtailed, exported to the national grid or stored**.

To prevent the village of Berchidda against blackout from the transmission line, the BK-SC implies increasing the electric storage capacity to 1 MWh (Maximum technical capacity). This storage capacity would partially cover the electricity demand during the most critical blackout event, therefore **there might be need for disconnection of some electric devices** from the electric network. Nevertheless, the increase of the electric battery capacity together with the other flexibility measures could allow reducing the needs of the effective capacity of the transmission line by 15%, from the current 1.5 MW to 1.28 MW.

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The ELC-SC shows that **fully electrifying the village of Berchidda would lead to higher electricity peak loads during winter** due to the use of electric HPs for space heating, and thus increasing the mismatch between local electricity production from the PV and electricity demand. In fact, the PV capacity remains the same as in the case of Ref-SC, and the use of batteries is 1 MWh. In parallel, there is an increase of the effective capacity of the transmission line from 1.5 MW to 2.1 MW, 40% more, to meet the new electricity demands. In the heating sector, there is **a high expansion of the use of thermal storage systems to take benefit of the electricity prices**, which are relevant for the electric HPs for the DHW. The full electrification of the transport will impact on the overall electricity demand profile, producing saw-tooth patterns.

In terms of decarbonization, in all the assessed scenarios there is a clear reduction of the overall CO_2 emissions compared to the base year. The Ref-SC and the BK-SC perform similarly with around 2,474 tons of CO_2, 34% less compared to 2017. The highest reduction takes place in the residential and service sectors due to the replacement of fossil boilers by HPs together with a slight reduction due to the inclusion of EVs. In the ELC-SC scenario, there is not any more direct CO_2 emissions because of the full electrification of the village. However, this scenario has the highest indirect CO_2 emissions due to electricity imports, accounting for 1,562 tons of CO_2.

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5/ Ispaster demo case

5.1. Overall pilot description

The village of Ispaster is in the province of Biscay (Spain), specifically in the Lea-Artibai region. It is 56 km away from the provincial capital, Bilbao, and has very few public transport routes. The village has a population of around 750 inhabitants living in twelve neighbourhoods. The main district is called Elexalde, with 350 inhabitants, a site of the townhall, public school, and cultural centre, as well as most of the public services.

Figure 107: View of the village of Ispaster

In 2014, the village launched a project to generate its own energy and become less dependent on energy from the electricity utility due to continuous power outages and failures in the energy service. Thus, a process to implement a self-production energy system started, consisting of two isolated energy island concepts: a hybrid DH network currently including 12 consumption points, and an isolated electricity micro-grid (i.e. not connected to the main grid) connected to PV which was developed between 2016 and 2019 combined with batteries that currently has 10 consumption points for public buildings.

Two biomass boilers provide most of the thermal energy to the DH complementarily supported by a solar thermal energy system that allows reducing the workload of the biomass boiler in summer. Consequently, almost the entire heat demand in summer can be covered, not relying on biomass. The network has around 12 m^3 of thermal storage consisting of water tanks. This hybridization (biomass boilers and solar thermal panels) and the utilization of storage have led to a significant reduction in the public energy consumption.

These projects prove the commitment of the village to help Ispaster becoming a clean and sustainable town and to encourage other projects that support this process. Those projects have also contributed to raising the awareness of the citizens to have a clear understanding of the benefits from renewable energy technologies.

5.2. Current energy characterization of the pilot – Base Year 2019

5.2.1. Annual energy assessment demand

Figure 108 shows the breakdown of the final energy demand by fuel and sector in the village of Ispaster, which is estimated in around 3,528 MWh. The selected reference year is 2019, since this is the last year with available data in terms of energy consumption by sector in the village.

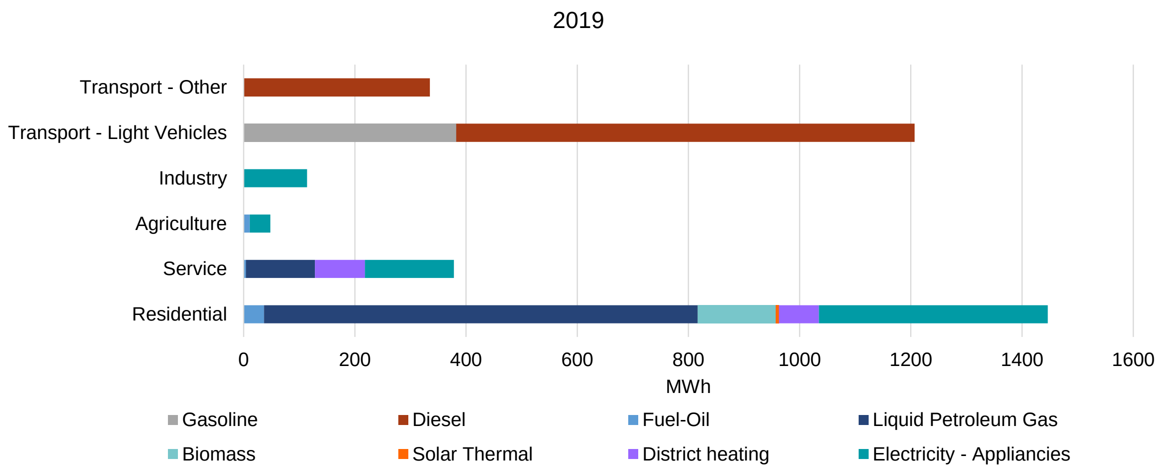

Figure 108: Energy demand by fuel and sector in 2019 in the village of Ispaster

The residential sector is the main energy consumer with an annual energy consumption of 1,447 MWh, that represents 41% of the overall energy consumption. In this sector**, liquid petroleum gas (LPG) is the main fuel** accounting 780 MWh representing 54% of the total fuel consumption. **Electricity consumption is used only by appliances** with a consumption of 1,164 MWh of electricity that represent a share of 28% of the total electricity demand. The transport sector is split in two subsectors: light vehicles, that encompasses all types of cars, and others, which includes heavy vehicles like trucks and tractors used in agriculture. In 2019, fuel consumption of light vehicles accounts for 1,207 MWh of fuel demand being the second most relevant sector. This sector is driven by fossil fuels only where diesel is the main one representing a share of 68% while the remaining part is gasoline. Fuel consumption for heavy vehicles is 100% diesel with 335 MWh. The service sector accounts for 378 MWh, with electricity consumption representing 42%. Like in residential sector, electricity is only used due to in appliances. LPG is the main fuel for heat production with a consumption of 124 MWh followed by DH with 90 MWh. Finally, industrial and agriculture sectors are the smallest ones in terms of energy demand, with a fuel consumption of 114 MWh and 48 MWh, respectively.

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CO_2 EMMISSIONS

Figure 109 shows the direct and indirect CO_2 emissions by sector of the base year in the village of Ispaster. The total CO_2 emissions account for 879 tons of CO_2, of which 182 tons of CO_2 are indirect emissions due to the electricity consumption from the national grid, while the remaining are direct emissions from the different sectors. In the calculation of the indirect CO_2 emissions, an emission intensity of electricity production 263 tons of CO_2 by MWh is considered, which is the average value for Spain in the period 2017-2019 (EEA, 2022). This is done to avoid possible fluctuations for 2019 and capture better the current trend. Direct CO_2 emissions from the transport and the residential sectors are the main CO_2 emission source, accounting for 409 and 194 tons of CO_2, respectively. Both sectors represent around 74% of the overall CO_2 emissions. There is around 1 ton of CO_2 emitted by the DH due to the use of a gas boiler as a back-up.

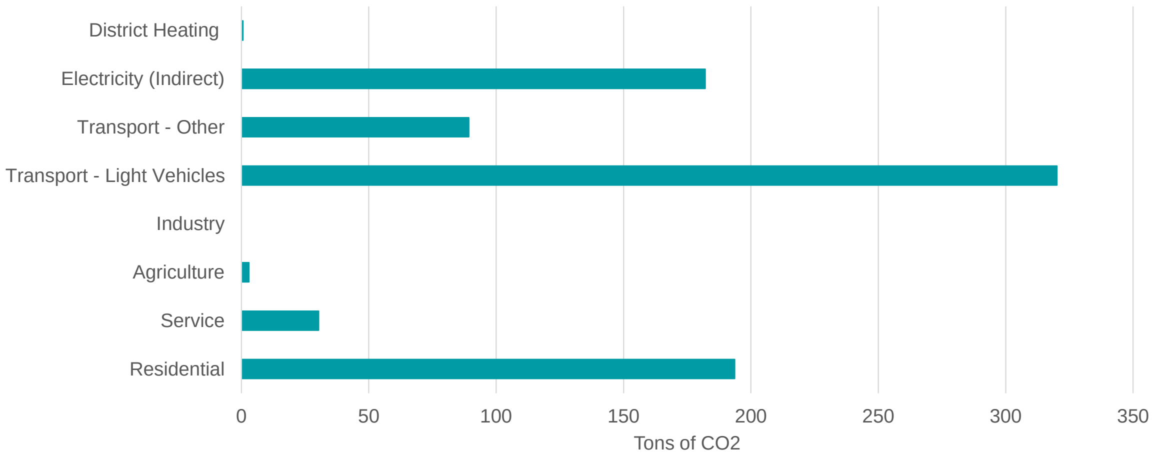

Figure 109: CO_2 emissions by sector of the base year in the village of Ispaster

ELECTRICITY DEMAND PROFILE

Figure 110 presents the estimated hourly electricity demand profile in the village of Ispaster. The total annual electricity consumption accounted for 723 MWh in 2019. For this year, there is available information about electricity consumption split by sector, type of consumer groups and specific electricity consumption by consumers groups in the service sector according to REE (Spanish national electric grid operator). However, there is not specific electricity consumption profiles for the village of Ispaster. In this context, **it is assumed that each consumer group follows the standard electric consumption profiles developed by REE** (REE, 2022). Hence, the electricity consumption profile refers to the sum of this standard profile, weighted by the energy consumer groups.

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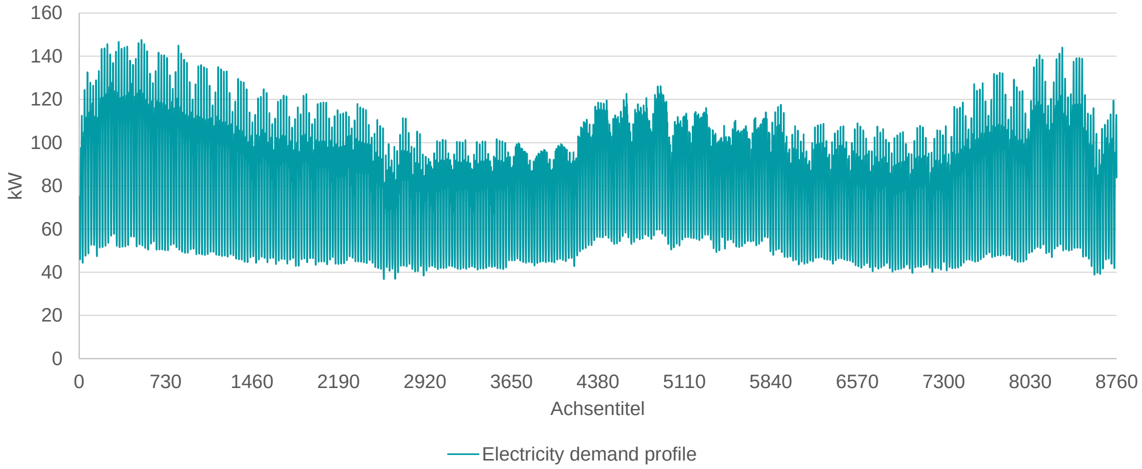

Figure 110: Electricity demand profile for the village of Ispaster

HEAT DEMAND PROFILE – SPACE HEATING AND DHW

The estimated hourly heat demand profile of the village of Ispaster is shown in Figure 111. The annual total heat demand corresponded to 1,191 MWh in 2019. There is not information about the hourly heat load profile of Ispaster. Therefore, **a synthetic profile was built based on combination of two independent profiles;** one that represents space heating and another one that represents DHW. **The profile for space heating was generated from the combination of the monthly HDD profile** based on the meteorological data of the closest weather station in the village of Bilbao (BizEE, 2022) and the hourly temperature profile for the village of Ispaster from PVGIS (JRC-European Commission, 2022). **The DHW profile follows the general DHW hourly resolution profile developed within the European REACT project** (REACT project, 2018). Finally, both profiles are normalized, weighted, and summed up to estimate the overall hourly heat demand profile. It is estimated that the space heating consumes 65% of the total heat demand and DHW 35%, according to the data for buildings in the Atlantic Zone from IDAE (IDAE - Instituto para la Diversificación y Ahorro de la Energía, 2022).

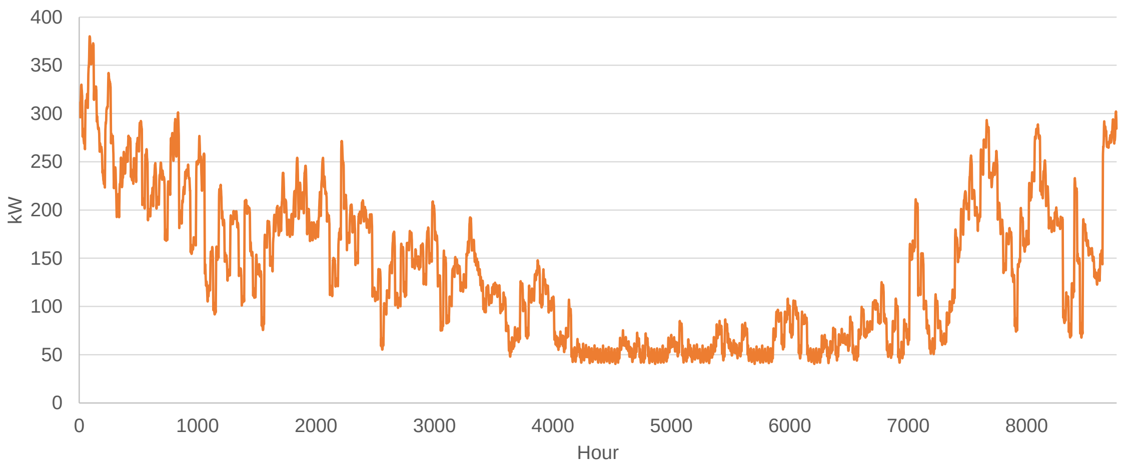

Figure 111: Heat load profile for the village of Ispaster

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OTHER ASSUMPTIONS CONCERNING THE TRANSPORT SECTOR

Transport sector is dominated by diesel and gasoline fuelled vehicles accounting 190 and 85 of light vehicles in 2019. Considering energy consumption for transport sector and the number of light vehicles, the average annual vehicle-kilometre (vkm) is estimated around 8,797 vkm in Ispaster.

5.2.2. Local heat and electricity production capacity

Figure 112 shows the local heat and electricity production as well as the transmission line capacity in the village of Ispaster in 2019. In this year, the village of Ispaster accounted for a total installed PV capacity of 28,3 kWp, that generates 29.7 MWh with 1050 FLH (full-load hours). PV panels are connected to electric batteries with an overall capacity of 178 kWh. The transmission line that connects the village to the national grid have an effective capacity of 112 KW, which is estimated to cover 80% of the current peak demand. In the heating sector, **single boilers are dominated by LPG-based boilers** with an installed heat capacity of 309 kW. **In the DH system, renewable fuels have the main role** with 300 kW biomass boilers and 42 kW solar thermal panels, however gas boiler is also relevant with 220 kW.

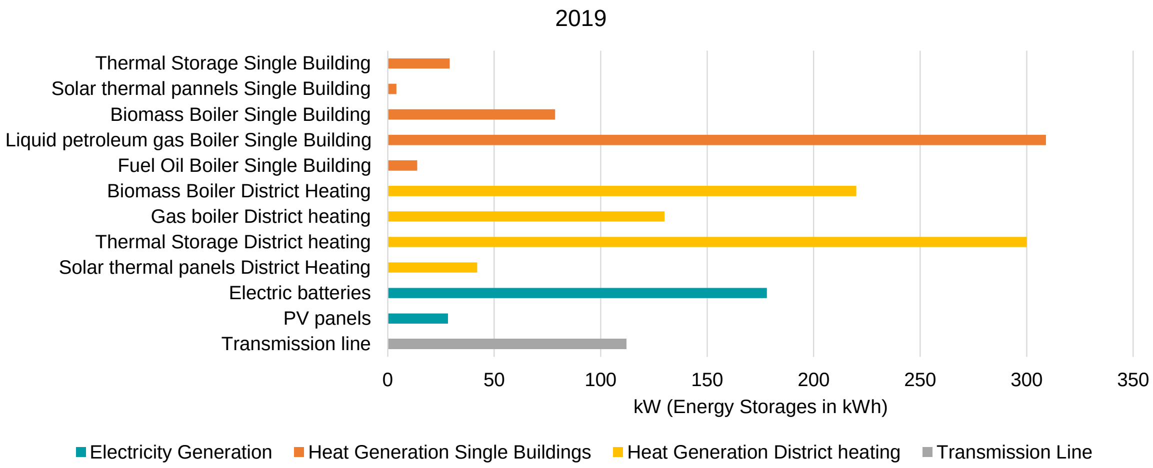

Figure 112: Local energy production capacity and transmission line capacity for Ispaster in 2019

ELECTRICITY PRICES PROFILE

The electricity prices profile for Spain in 2030 is presented in Figure 113. **These electricity prices of Spain in 2030 are based on EU28-Balmorel model** as it was mentioned in Section 2.3. It is expected that Spanish electricity prices will have a high fluctuation due to increase of vRES connected to the national grid being average prices around 34.8 €/MWh in 2030. In this context, **electricity prices in Spain, as well that the transmission line capacity** which connects the village of Ispaster to the national grid, **determine how the community interacts with its national market**, more precisely how exchange (imported/exported electricity) takes place under a least-cost solution framework.

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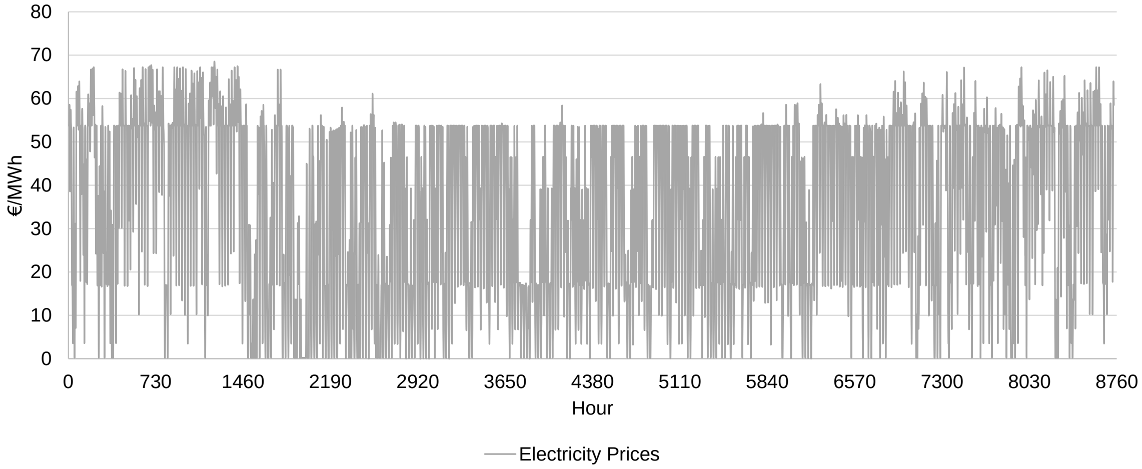

Figure 113 Electricity prices profile for Spain in 2030

SOLAR PROFILE

Figure 114 shows the hourly electricity production profile for PV panels in the village of Ispaster. This profile was created using the PVGIS tool (JRC-European Commission, 2022) taking as reference a crystalline silicon PV panel with a nominal power of 1 kWp and solar data from 2016. This PV profile is also used to define thermal energy production from thermal solar panels.

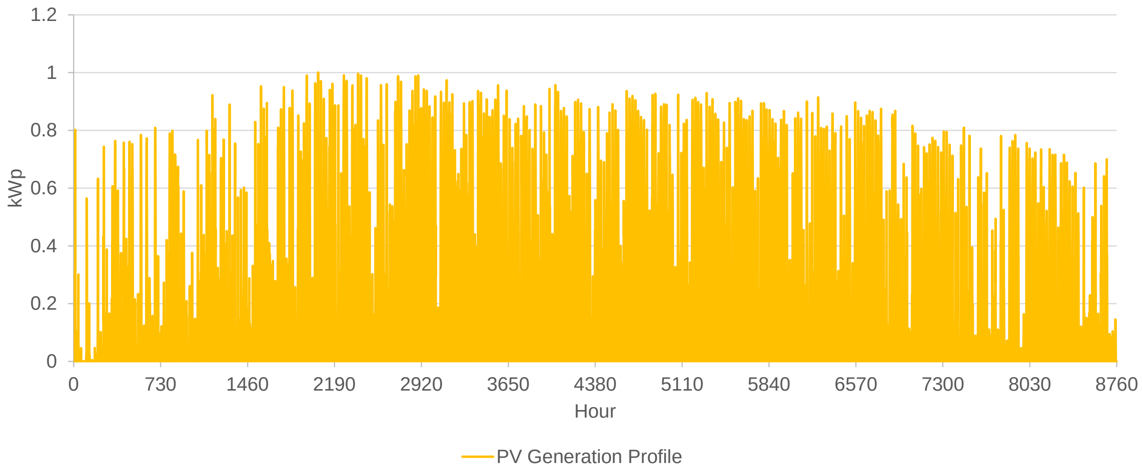

Figure 114 Electricity production profile for PV panels in Ispaster (normalized to 1 kWp)

5.3. Scenario definition

Three scenarios are explored within the LocalRES project for the village of Ispaster. The goal of these scenarios is to define the least-cost solutions for different possibilities in the long-term perspective (2030) on how the establishment of a hypothetical energy community including all the village can perform and support the energy decarbonization of Ispaster. In this analysis, the impact of flexibility measures such as demand side management (DSM), smart charging for EVs, energy storage, HPs as well as the use of PV panels and DH systems are explored in each scenario. As for the rest of demo sites, these scenarios were built together with local stakeholders to reflect their view about how the energy transformation in the pilot could be:

- ***Reference Scenario (Ref-SC):*** In this scenario, the village concentrates their efforts in **replacing part of the fossil fuel boilers by HPs, expanding the DH network and promoting the use of EVs**. This scenario also includes the **increase of vRES capacities** and the **use of CHP** systems, as well as the implementation of flexibility measures (smart charging for EVs, DSM and of energy storage systems, such as batteries and thermal energy storage systems).
- ***Blackout Scenario (BK-SC):*** In this scenario, the village keeps their effort on the replacement of part of the fossil fuel-based boilers by HPs, on the expansion of the DH network and the promotion of the use of EVs in the same way as Ref-SC. In addition, it is explored **how flexibility measures and local resources can support mitigating blackout events and reduce the dependence** from the national transmission grid. The black-event duration was considered 1 hour to be conservative, as these events typically have a lower duration.
- ***Energy island Scenario (EI-SC):*** In this scenario, the village explores the **full independence from the national grid, working as energy island**. For that, all individual heaters are replaced by HPs, the DH network is expanded, the full electrification of the light vehicles takes place and biodiesel is used in the other transport modes and agriculture. In addition, it is explored how flexibility measures, local resources and CHP plants can support the full independence from the national grid

Table 5 summarizes the technical description for the village of Ispaster's scenarios. For all the scenarios the maximum capacity for PV is 330 kWp and DH should cover 72% of the heat demand of the village. In the Ref-SC and the BK-SC the replacement of fossil fuel-based boilers by HPs is limited to only 10% of the current heating boilers. **There is a high interest in the use of biomass-powered CHP**, with a CHP ratio of 11 (i.e. 5 kW_{el}/55 kW_{th}). In these two scenarios, the penetration of 22% of EVs follows the national target according to (European Commission, 2022). **E-vehicles have smart charging, being able to charge the batteries according to the local condition of grid and electricity prices**. The EI-SC goes further with a full electrification of the individual heaters and of the transport sector. In this case, EVs also allow discharging the batteries to the electricity grid in case of need (V2G). CHP plants are connected to the CHP, with a CHP ratio of 3 (20 kW_{el}/60kW_{th}), giving more relevance to the electricity production.

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Table 5: Scenario characteristics in 2030 for Ispaster demo case

	Ref-SC	BK-SC	EI-SC
Max. allowed PV	Up to 330 KWp	Up to 330 KWp	Up to 330 KWp
Fossil Fuel	Low remaining	Low remaining	100% reduction
Max. allowed electric batteries	No restrictions	No restrictions	No restrictions
Fossil Fuel	Low remaining	Low remaining	100% reduction
Heat pumps	Replace 10% of current boilers	Replace 10% of current boilers	Replace all out of DH
DSM	Available	Available	Available
DH expansion	72% of heat demand	72% of heat demand	72% of heat demand
Biomass CHP ratio[5]	11 (5 kWe/55kWth)	11 (5 kWe/55kWth)	3 (20 kWe/60kWth)
Max. allowed geothermal HP	Up to 30 kW	Up to 30 kW	No limit
Thermal solar	No restrictions	No restrictions	No restrictions
Biomass Boiler	No restrictions	No restrictions	No restrictions
Max allowed individual thermal solar	18 KW	18 KW	18 KW
E-vehicles	22% of light vehicles	22% of light vehicles	100% of light vehicles
Type of e-charge	Smart charging	Smart charging	V2G
Other transport modes	Diesel fuel	Diesel fuel	Biodiesel fuel
Transmission capacity to national grid	112 kW (80% of max current peak)	Minimized	No connection
Blackout event	N/A.	1 hour	N/A.

[5] CHP ratio: Ration between heat production capacity and electricity production capacity

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5.4. Energy demand projection in 2030

Several drivers and assumptions are needed to establish and to estimate the future energy demand forecast of the village of Ispaster in 2030.

The residential sector is the largest energy consumer sector. **The estimation for the future DHW and electricity demand is based on population forecasting, while space heating demand is linked to the refurbishment rate** of buildings. It is expected that the population in the village of Ispaster will increase around 7% in 2030. Residential buildings will increase due to the construction of a new apartment building with 10 to 12 apartments. This leads to an increase of the heat demand for space heating. However, **the refurbishment of old buildings together with the better energy performance of the new buildings limit the increase of the heat demand** for space heating from the current 625 MWh to 647 MWh.

In the service sector, it is assumed that the future energy demand will increase around 5% in 2030. This estimation is associated to the increase of the population. However, the growth of the demand will be lower than the one for the population. **The future energy demand estimation for light vehicles in the transport sector also follows population forecast** as it is assumed that habits of local drivers do not change. Finally, the future energy demand of other sectors (industry, agriculture, and other transport vehicles) remains the same because no changes are expected.

Accordingly, two future energy demand scenarios named DMD-Ref and DMD-ELC for the different energy sectors are estimated in 2030. These scenarios are built by combining different drivers to estimate future demand by sectors in the village of Ispaster. Furthermore, they consider scenario specifications required as well as the impact of shifting to more efficient technologies.

Figure 115 shows the DMD-Ref demand scenario, which is considered in the Ref-SC and the BK-SC to capture the 22% of EVs penetration as well as the 10% of replacement of fossil fuel-based boilers by HPs and the expansion of DH, covering 72% of heat demand.

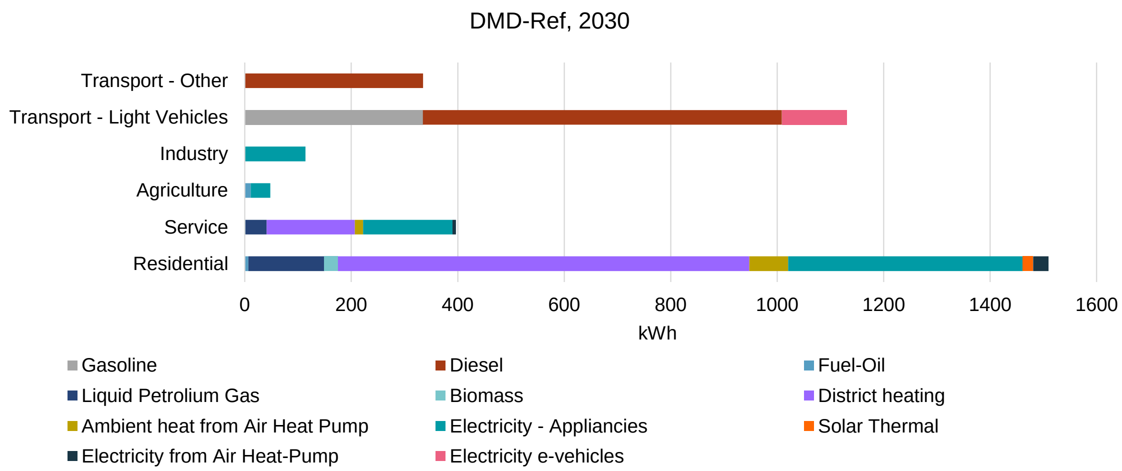

Figure 115: DMD-Ref demand scenario in the village of Ispaster in 2030

The DMD-Ref implies an overall fuel demand of 3,534 MWh in 2030 (without electricity and DH distribution losses) that remains almost the same compared to 2019. This is **because the energy demand increases in the residential and service sectors but this is compensated by the reduction of energy demand for light vehicles** in the transport sector. Despite the number of vehicles is higher in 2030, there is a reduction of 6% of the energy demand as the EVs are more efficient than the ICE vehicles. Due to the electrification of heating and transport sectors, electricity demand grows to 917 MWh sharing 26% of the total energy demand.

The residential sector is the largest one with a total fuel consumption of 1,510 MWh. This amount represents an increase of 4% compared to 2019. **DH is the highest contributor** with 773 MWh covering 51% of the energy demand. Air-source HPs provide 103 MWh, of which 29 MWh is accounted for electricity ,and the remaining energy comes from heat extraction from the ambient air.

The service sector accounts for 396 MWh in 2030 representing an increase of 5% compared to 2019. In the same way as the residential sector, DH is the highest contributor to cover the energy demand with 166 MWh and a share of 42%. Also, air-source HPs play an important role providing 22 MWh of heat, of which 6 MWh comes from electricity. Finally, the energy demand for the industry, agriculture, and other transport systems remains the same as in 2019.

Figure 116 represents the DMD-EI scenario. This scenario refers to the energy projections for the IE-SC, in which the village of Ispaster is fully independent from the national grid.

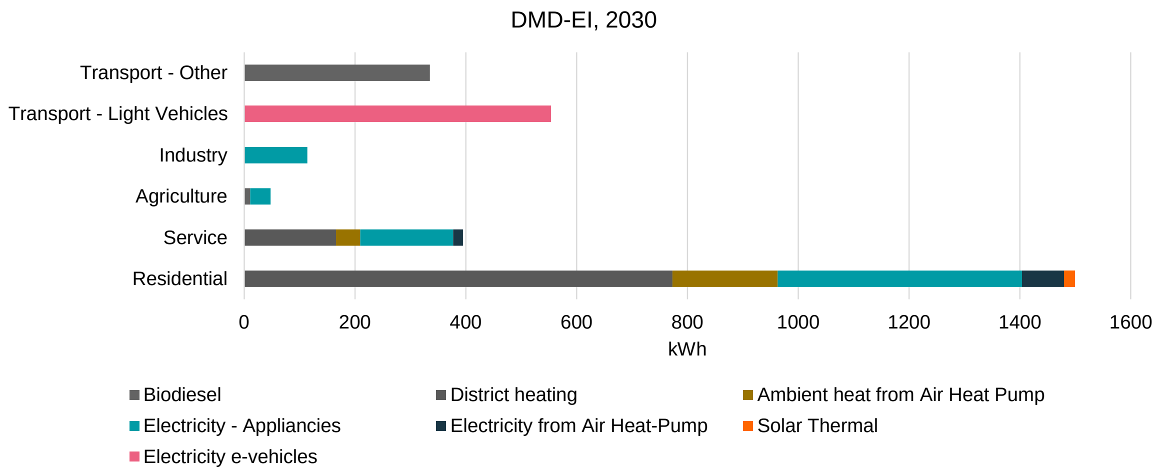

Figure 116: DMD-EI demand scenario in the village of Ispaster in 2030

DMD-EI scenario implies an overall fuel demand of 2,944 MWh (without electricity and DH distribution losses) that represents 83% of the total energy demand compared to 2019. This happens mainly due to the electrification of the transport sector for light vehicles that causes a reduction of 54% of the energy demand in 2030. Due to the electrification of the heating and transport sector, the electricity demand grows up to 1,407 MWh, representing 48% of the total energy demand.

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The residential sector remains the largest energy consumer sector with 1,499 MWh. This amount represents an increase of 4% compared to 2019. As in the DMD-Ref scenario, DH remains the same, being the highest contributor to cover the energy needs with 773 MWh. Heat provided by air-source HPs grows to 266 MWh, of which 76 MWh comes from electricity and the remaining part is for the heat extraction from the ambient air.

The energy demand for the service sector remains the same as in the DMD-Ref, accounting for 395 MWh with a slight reduction due to the use of air-source HPs. In this case, DH is also the highest contributor with 166 MWh. Finally**, biodiesel is used to replace diesel fuel in the industry, agriculture, and other transport systems** to contribute in the decarbonization of these sectors. However, the energy demand remains the same compared to 2019 as the boilers and ICE driven by biodiesel have almost the same efficiencies as the ones driven by diesel.

5.5. Results and discussion

In this section, the simulation results for the Ref-SC, BK-SC and EI-SC are presented. The results address how the electricity and heating demands in the village of Ispaster are covered by local energy resources and production technologies as well by different flexibility measures such as storage, power exchange (imports/exports) and DSM.

5.5.1. Ref-SC

Figure 117 shows the overall local heating and electricity production and the transmission line capacity in the village of Ispaster in the Ref-SC. PV experiences a high expansion with an installed capacity of 410 kWp compared to the 28 kWp in 2019. In parallel, 413 kWh of electric batteries is necessary to balance the electricity system, that represent 37% more in comparison to 2019.

The heating sector has a high transformation due to the expansion of the DH in the village. The overall installed capacity is 382 kW of which biomass boiler is the main technology with a capacity of 255 kW, followed by a CHP system with 55 kW thermal and 5 kW electrical capacity. Individual heating systems connected to buildings account for a total capacity of 128 kW, of which 50% are driven by fossil fuels. HPs play a decisive role in the heating sector with 73 kW, in the DH system and in individual buildings. Despite the solar thermal capacity remains the same in DH, there is a growth of single systems up to 13 kW in 2030. However, **the most significant development of thermal storage takes place mainly in the DH to allow balancing heat production properly due to the inclusion of the CHP system.**

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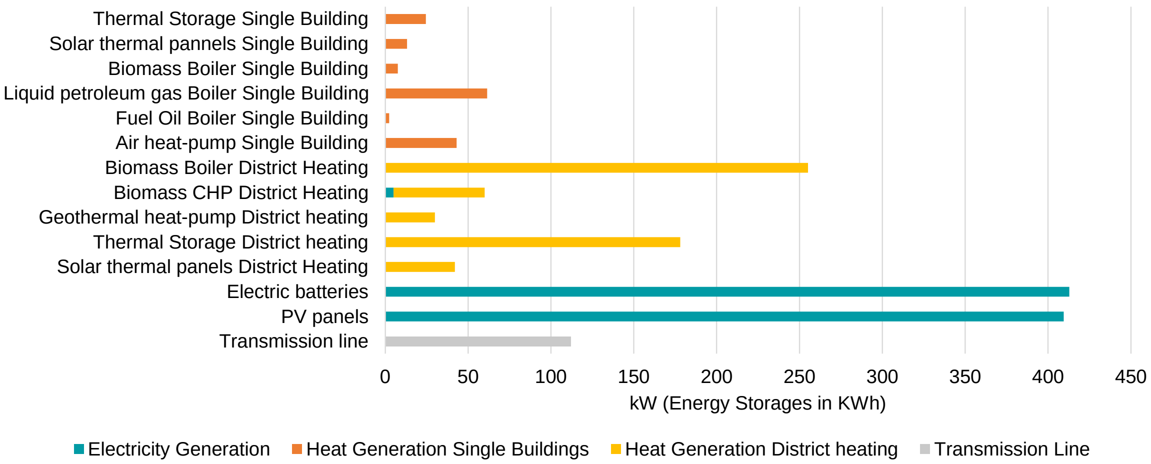

Figure 117: Installed local heat and electricity production capacities by technology and electricity transmission line capacity according to the Ref-SC in the village of Ispaster in 2030

ELECTRICITY SECTOR

Figure 118 shows the annual electricity demand per week in the Ref-SC by different consumption technologies in the village of Ispaster in 2030. The total electricity demand is estimated as 981 MWh (including 3% of electricity distribution losses) on an annual basis. **Appliances are the main electricity consumers** with 783 MWh representing 80% of the total electricity demand. EVs are the second highest consumer with an electricity consumption of 120 MWh. The remaining consumption is due to the use of HPs in individual systems in buildings or district heating HP, consuming 35 MWh and 41 MWh, respectively. Electricity consumption of HPs is low because of the large DH expansion that hinders the expansion of HPs. This results in a reduction of the utilization of DSM as a flexibility option, being able to balance only 3 MWh along the year, that represents 0.3% of the total demand.

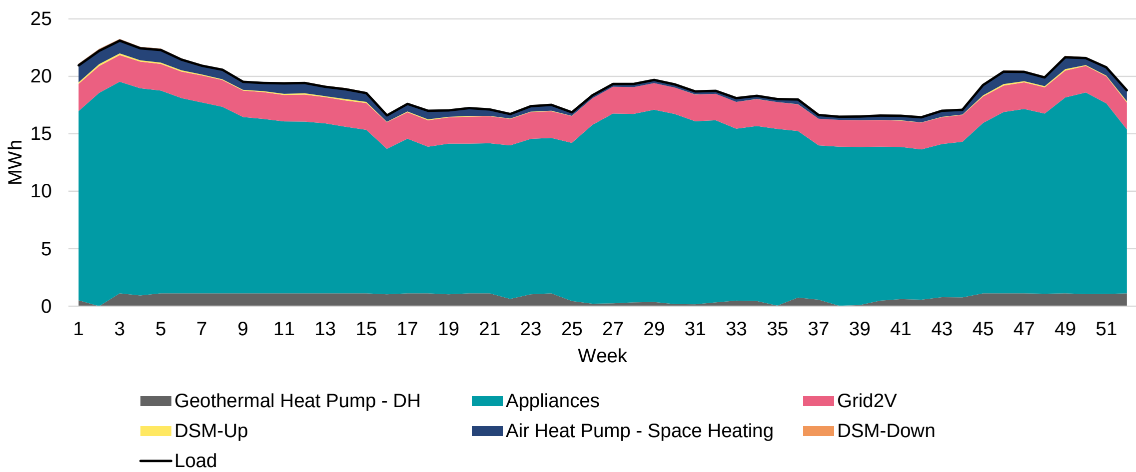

Figure 118: Annual electricity demand by technology according to the Ref-SC in Ispaster in 2030

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Figure 119 and Figure 120 illustrate hourly electricity demand profiles for the village of Ispaster for the last two weeks of January[6] and the first two weeks of July, illustrating winter and summer periods in 2030, respectively. Figure 119 shows that **DSM has low impact on the modification of the overall electricity demand profile**. Both figures show **the charging of EVs produces a saw-tooth consumption profile** due to the high number of EVs connected to the grid and to the use of smart-charging in which the batteries are charged in the moment of the day with the lowest electricity prices. The peak loads caused by EVs can represent up to 65% of the overall electricity demand in some hours.

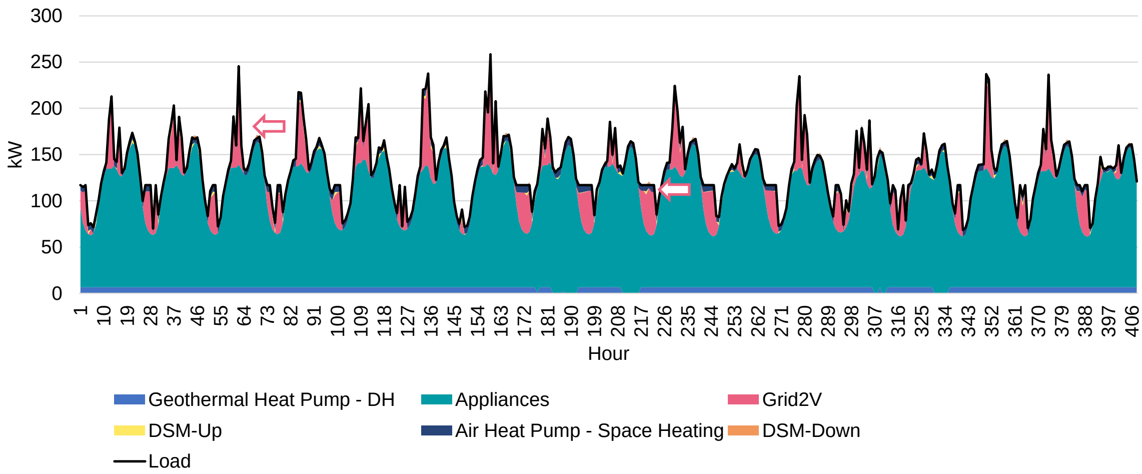

Figure 119: Hourly electricity demand in the last two weeks of January for the Ref-SC in Ispaster in 2030

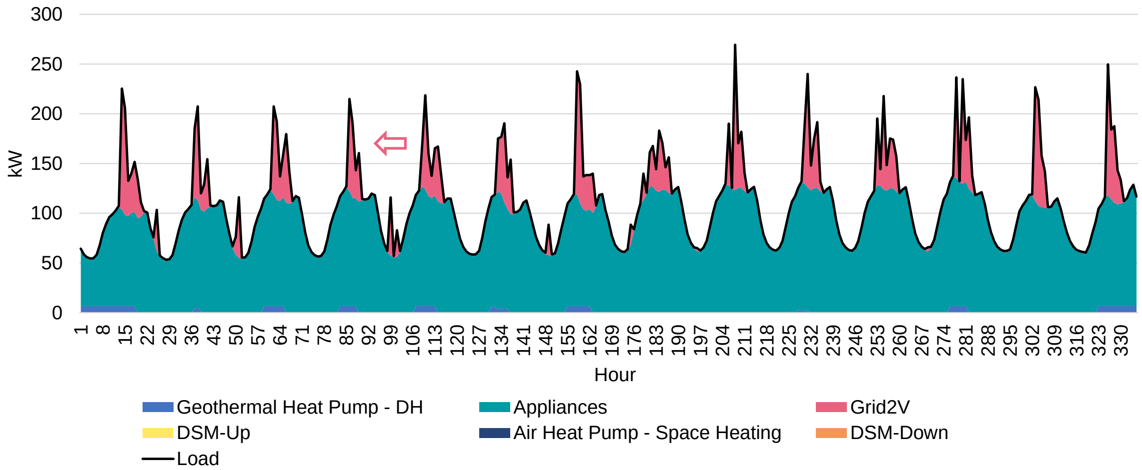

Figure 120: Hourly electricity demand in the first two weeks of July for the Ref-SC in Ispaster in 2030

[6] The last two weeks of January are chosen as according to the BK-SC during this period highest critical blackout event can take place.

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Figure 121 shows the annual electricity supply per week in the Ref-SC from local resources, imports and exports as well as the charging and discharging of batteries to balance the electricity system in 2030. Positive values concern to electricity supply of different options to meet the electricity demand, whereas the negative values represent the electricity that is either stored in batteries or exported. The annual generated electricity in the village of Ispaster is 564 MWh equivalent to 58% of the total electricity demand (including transmission losses). **PV panels are the main production systems** with an electricity production of 525 MWh, and 93% of the total electricity production, and the **CHP system is responsible for producing the remaining part**. The annual electricity imports are 612 MWh, and the highest dependence from the national electricity grid occurs during the winter period. In fact, during the first week of January, electricity import represents 19 MWh, 88% of the total electricity demand. Total electricity exports account for 151 MWh, and the highest exports take place during the second week of August with 6 MWh, 30% of the total electricity demand. Finally, the use of electric batteries allows balancing around 201 MWh at annual basis.

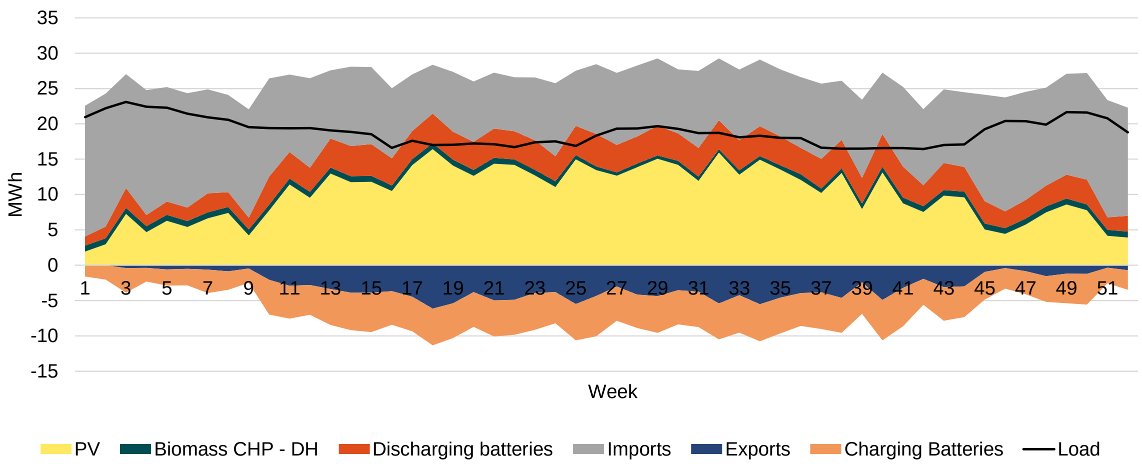

Figure 121: Annual electricity supply according to the Ref-SC in the village of Ispaster in 2030

Figure 122 and Figure 123 illustrate hourly electricity supply profiles for the last two weeks of January and the first two weeks of July, illustrating winter and summer periods, respectively. Both figures show how **the electricity production surplus from PV panels can be stored in batteries to be consumed in another time or exported to the national grid**. This effect happens more often during the summer periods as the electricity production from PV is higher. **During the summer, batteries are used to trade electricity with the national grid** by charging the batteries from the national grid when electricity prices are low and discharging to the national grid when the electricity prices are high. The CHP system accounts for 5 kW electric capacity, relatively small compared to the overall demand. During the winter periods, the CHP provides electricity constantly, however during summer period the electricity production is intermittent. This is **because during summer period there is an excess of heat production** due to the lower heat demand. The higher production of the heat comes from other sources such as solar thermal panels, making CHP system less necessary and affecting its electricity production.

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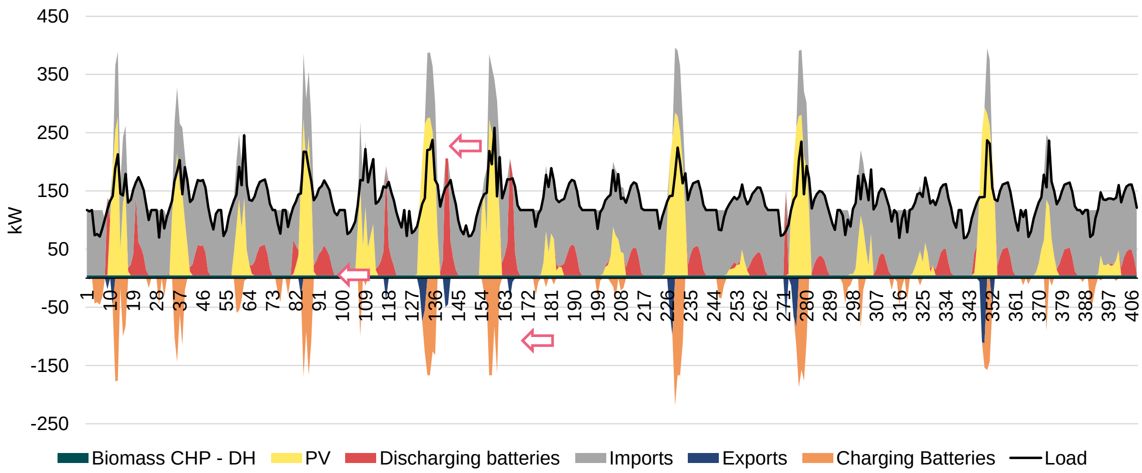

Figure 122: Hourly electricity production in the last two weeks of January for the Ref-SC in Ispaster in 2030

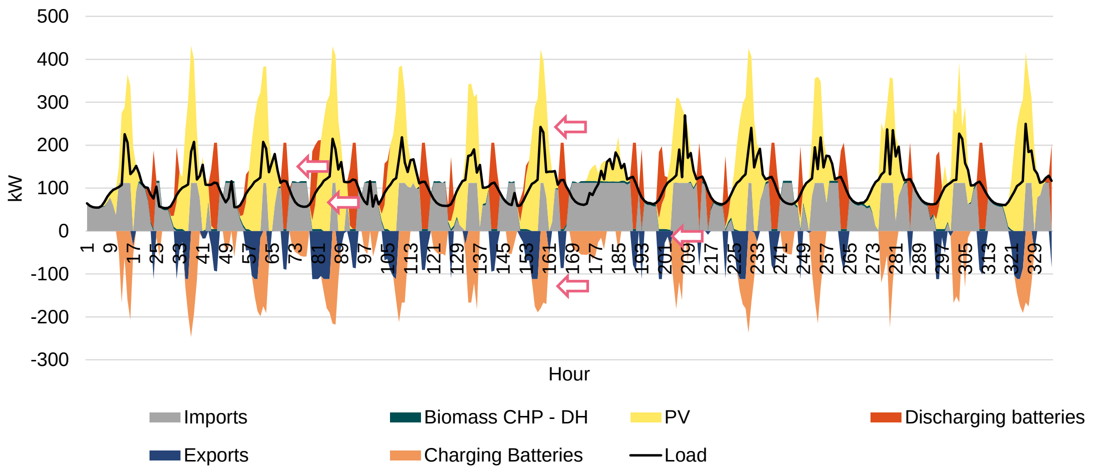

Figure 123: Hourly electricity production in the first two weeks of July for the Ref-SC in Ispaster in 2030

HEATING SECTOR

Figure 124 shows the annual heat supply in the Ref-SC per week by different heat production technologies in 2030. In the village of Ispaster, **the heat is produced and consumed locally, hence heat trade with an external network out of the community is not possible**. The total heat production is estimated as 1,450 MWh (including 15% distribution losses) on an annual basis. **DH is the main heat source** with 1,102 MWh, where biomass CHP and biomass-based boilers share equally around 39% of this total. Geothermal HPs contribute with 185 MWh. Among the single heat systems LPG boilers are the main source providing 175 MWh followed by air-source HPs with 124 MWh. The overall heat production for solar thermal panels is 72 MWh of which 53 MWh are allocated in the DH system. Aligned to this, heat storage systems can balance 24 MWh heat, where 21 MWh are used for the DH.

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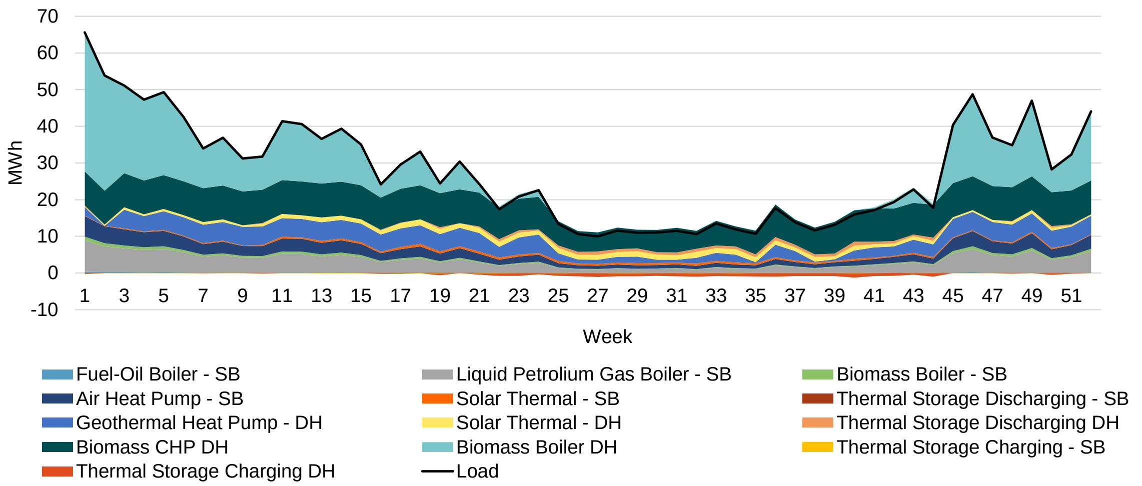

Figure 124: Annual heat production by technologies according to Ref-SC in Ispaster in 2030

Figure 125 and Figure 126 illustrate hourly heat production profiles for the village of Ispaster for the last two weeks of January and the first two weeks of July, illustrating winter and summer periods in 2030, respectively. The thermal storage is in operation only few hours during the winter period due to the low solar radiation. In the summer period, heat storage systems are more active, being able to store the surplus of heat production from the solar panels and shift this heat to be used in a different time. In fact, **in the DH system, the heat surplus from the CHP system is also stored to use this heat during moments when solar production is not able to cover the demand**. In summer period, while the geothermal HP in the DH systems is in operation during moments when electricity prices are low only. The CHP plant generates heat only in times when electricity prices are high to sell the electricity to the national grid.

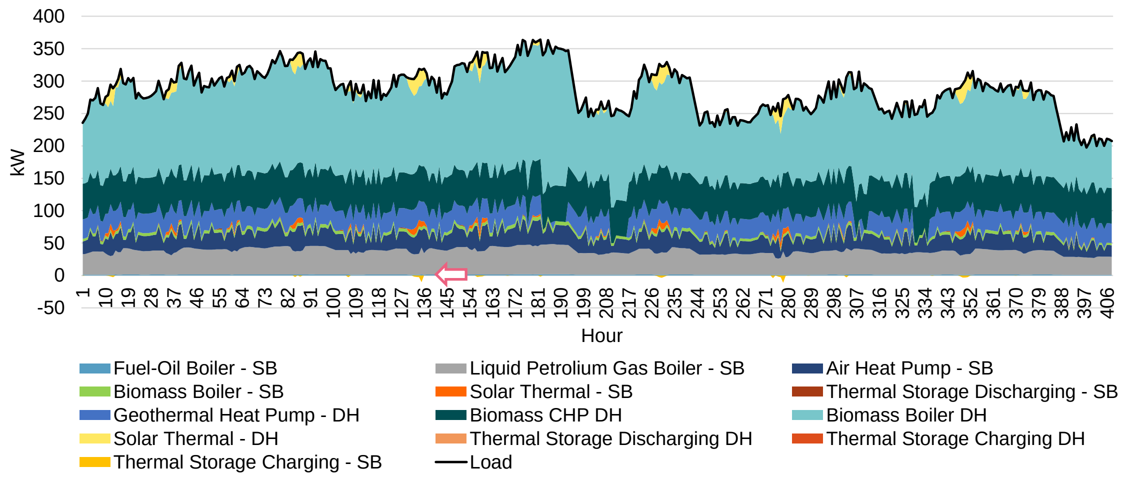

Figure 125: Hourly heat production in the last two weeks of January according to the Ref-SC in the village of Ispaster in 2030

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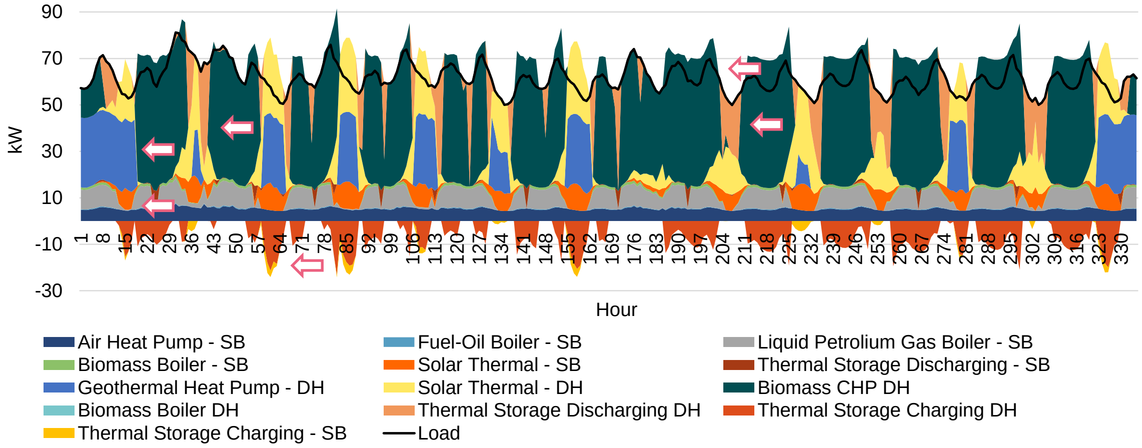

Figure 126: Hourly heat production in the first two weeks of July for the Ref-SC in Ispaster in 2030

CO_2 EMMISSIONS

Figure 127 shows the direct and indirect CO_2 emissions by sector of the Ref-SC scenario in the village of Ispaster. The total CO_2 emissions account for 433 tons of CO_2, of which 28 tons of CO_2 are indirect emissions due to the electricity consumption from the national grid, while the remaining are direct emissions from the different sectors. In the calculation of the indirect CO_2 emissions in 2030, an emission intensity of electricity production of 60 tons of CO_2 by MWh is considered based on the Spanish NECP (European Commission, 2022). There is a reduction of 47% in the overall CO_2 emissions compared with the base year due to the expansion of local PV as well as the DH driven by renewable energy sources. The high reduction of the intensity of electricity production in the national grid also has a high contribution in the reduction of the indirect CO_2 emissions. The transport sector is the main emitting sector with overall direct CO_2 emissions of 357 tons of CO_2, representing 82% of the overall CO_2 emissions under this scenario.

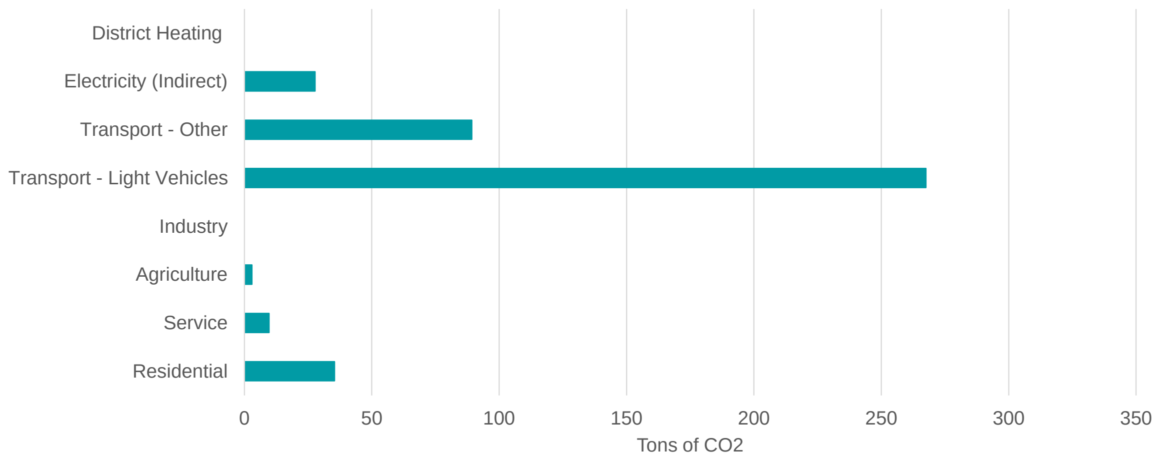

Figure 127: CO_2 emissions by sector of Ref-SC scenario in the village of Ispaster

5.5.2. BK-SC

This scenario explores how flexibility measures and local sources can support to prevent blackout events and reduce the dependence on the national transmission grid. To assess how the system performs within this event, **a blackout is forced in the transmission line of the village of Ispaster during the most critical time**. Furthermore, **this event is combined with the identification of the minimum transmission line capacity needed**.

Residual load is used as indicator to identify the most critical time when the village of Ispaster is more dependent on the transmission line. The residual load is defined as current load at each time minus the local electricity production from vRES, which is PV in this case.

Figure 128 shows the residual load for the village of Ispaster. The positive values are the hours when the load is higher than the electricity production from PV, implying a high dependence on the transmission line and where the flexibility measures such as electric batteries can be more active to prevent the blackout. Negative values represent the PV surplus, meaning that local electricity production from PV panels exceeds the load. **The highest positive value of the residual load is 173 kW and takes place during the 20th of January** (hour number 501 of the year). At this time, in the model **a blackout is forced avoiding exports and imports of electricity** to the village of Ispaster.

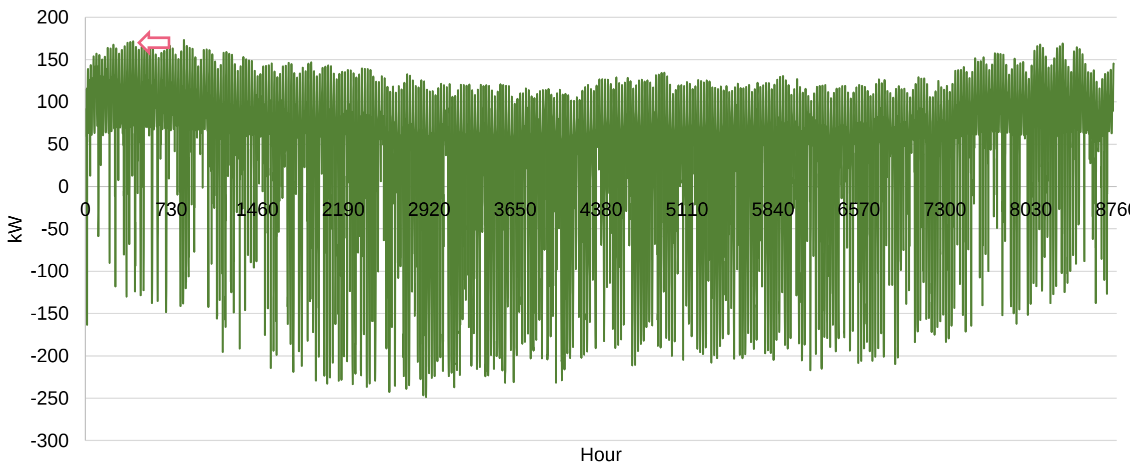

Figure 128: Residual load for the village of Ispaster in 2030

Figure 129 shows the overall local installed heat and electricity production capacities and transmission line capacity in the BK-SC in 2030. In this scenario, **PV capacity experiments a higher expansion compared to the Ref-SC** growing this capacity to 647 kWp. In parallel, 880 kWh capacity of electric batteries is necessary to balance electricity system and blackout prevention. **The different flexibility measures allow reducing the effective transmission capacit**y with the national grid by means of 7% from 112 kW to 104 kW.

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Like in the Ref-SC, the heating sector has a high transformation due to the expansion of the DH in the village. The DH capacity increases up to 408 kW in the BK-SC, where the CHP system has 5 kW electrical and 55 kW thermal capacity and biomass boiler capacity rises to 281 kW. Individual heating systems connected to building, like in the Ref-SC, account for a total capacity of 128 kW, of which 50% are driven by fossil fuels. According to this scenario, HPs play an important role with 73 kW for DH and single systems.

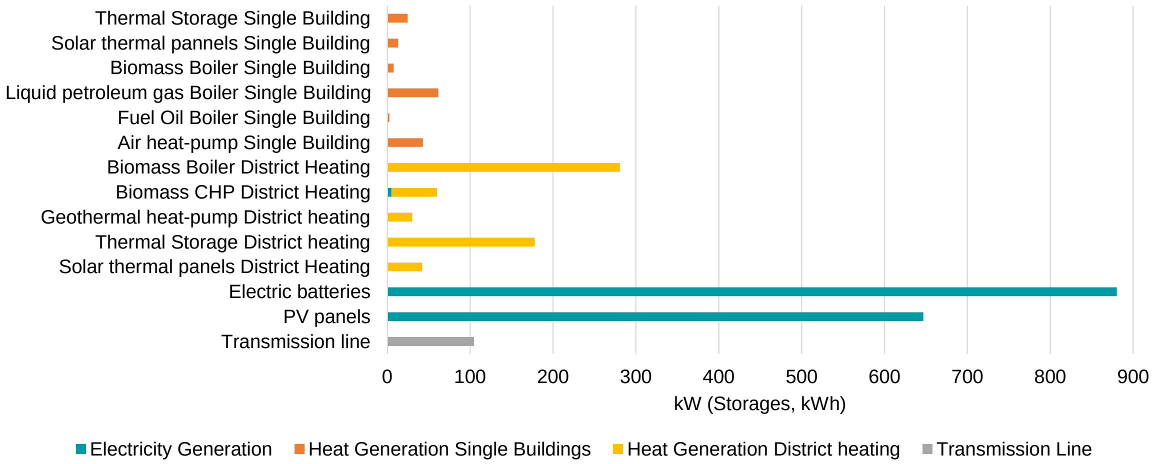

Figure 129: Local heat and electricity production capacities by technology and electricity transmission line capacity according to the BK-SC in the village of Ispaster in 2030

ELECTRICITY SECTOR

Figure 130 shows the annual electricity demand in the BK-SC by different type of end-use technologies per week in 2030. This electric load is the same as in the Ref-SC, as both scenarios must cover the DMD-Ref load projection. Likewise, the total annual electricity demand for the BK-SC is estimated at 981 MWh (including 3% of electricity distribution losses) in 2030. However, in this case **additional electric power capacity is needed to cover the demand during the simulated blackout event**. As in the Ref-SC, appliances are the main electricity consumers with 783 MWh sharing 80% of the total electricity demand. **E-vehicles are the second highest consumer** with 120 MWh. The remaining consumption due to the use of HPs and DSM do not have a high impact to change the overall electricity profile.

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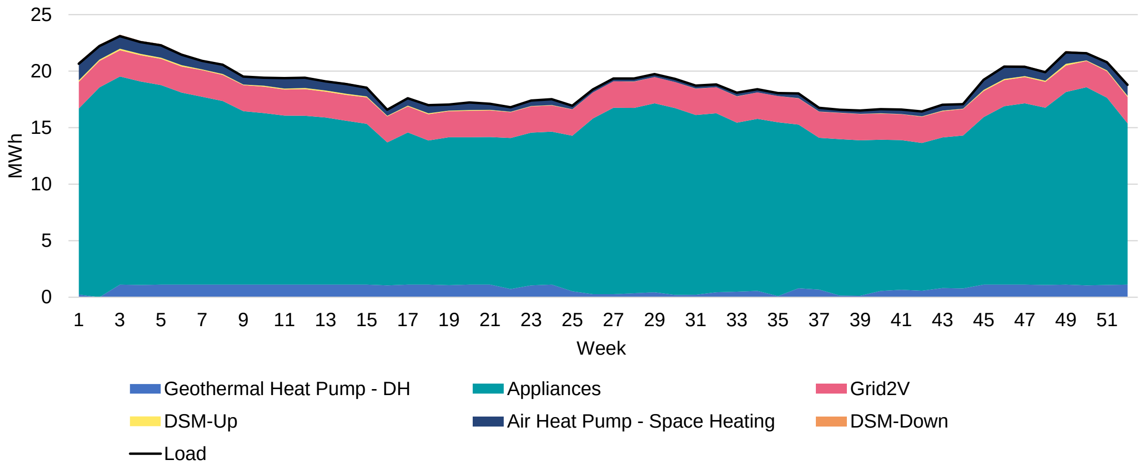

Figure 130: Annual electric demand by end-use technologies according to BK-SC in Ispaster in 2030

Figure 131 and Figure 132 illustrate hourly electricity demand profiles for the last two weeks of January7 and the first two weeks of July in 2030, representing winter and summer period, respectively. Figure 81 also shows the simulated blackout period on the 20th of January (hour 501 of the year, hour 165 in Figure 131). **During the blackout event the local energy system of Ispaster can cover the requested demand due to the additional capacity increase**. Like in the Ref-SC, both figures show that the charging of EVs affects the overall load profile, producing a saw-tooth effect due to the high number of EVs connected. However, these **load peaks of EVs are reduced because of the availability of V2G technologies**, which is more necessary in this scenario, as the transmission line capacity is reduced to 104 kW. The impact of DSM flexibility measures in the overall electricity profile is low due to the reduced relevance of HPs in the system.

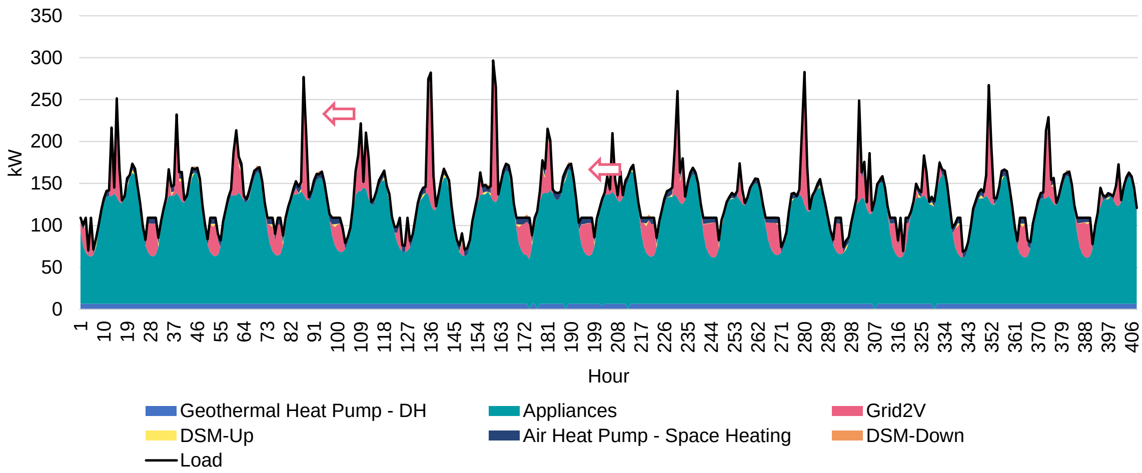

Figure 131: Hourly electricity demand by end-use technologies in the last two weeks of January according to the BK-SC in the village of Ispaster in 2030

[7] The last two weeks of January are chosen as it is during this period where the highest critical blackout event can take place based on the BK-SC.

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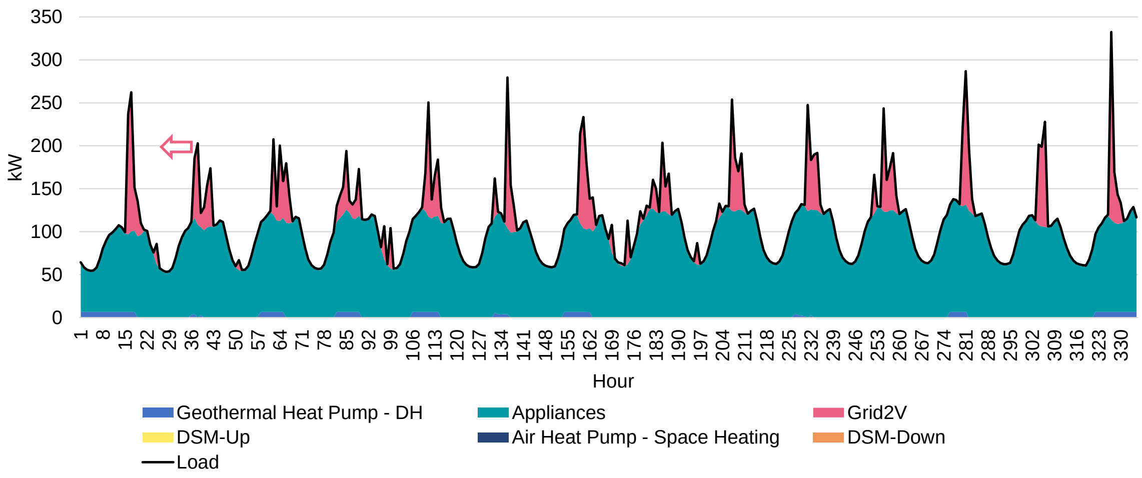

Figure 132: Hourly electricity demand by end-use technologies in the first two weeks of July according to the BK-SC in the village of Ispaster in 2030

Figure 133 shows the annual electricity supply in the BK-SC from local sources, imports and exports, as well as the charging and discharging of batteries needed to cover the electricity supply per week in 2030. Positive values are electricity supply components, whereas the negative ones represent the demand components such as charging of batteries or electricity exports. **The annual locally-generated electricity is higher than in the case of the Ref-SC** and accounts for 807 MWh equivalent to 82% of the total electricity demand (including transmission losses). Here, **PV panels have the main production** with 768 MWh, corresponding to 95% of the share in the total electricity production, whereas the remaining part is covered by the CHP. In parallel, **the supplementary capacity of electric batteries to prevent the possible blackout leads to additional benefits to balance supply and demand** by shifting 361 MWh electricity, 63% more in comparison with the Ref-SC. Due to the reduction of the transmission line capacity, annual electricity imports decrease slightly compared to Ref-SC accounting for 510 MWh. However, the exports grow to 268 MWh due to the possibility of a higher electricity production from PV.

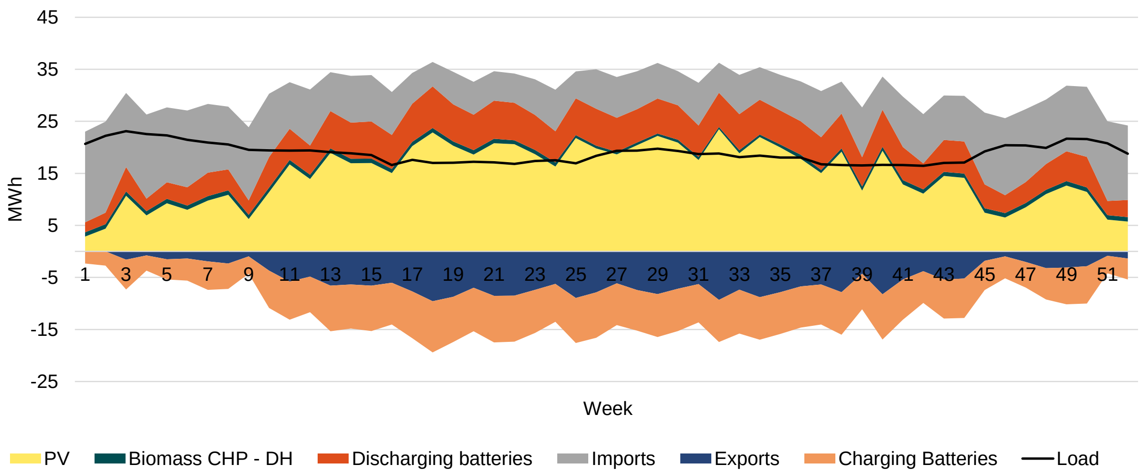

Figure 133: Annual electricity supply by technologies according to BK-SC in Ispaster in 2030

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Figure 134 and Figure 135 illustrate hourly electricity production and supply profiles for the last two weeks of January and the first two weeks of July, representing the winter and summer periods, respectively. Figure 84 shows that simulated blackout takes place on the 20th of January (hour 501 of the year, hour 165 in Figure 134). This figure also shows that **there is enough electric storage capacity to cover the most critical blackout period**. Both figures indicate how **the surplus of electricity production from PV can be stored in batteries to be consumed in another time or exported to the national grid**. In this case, the storage systems exchange electricity with the national grid more often, including in winter times. Like in the Ref-SC, the CHP system as an electric capacity of 5 kW, relatively small compared to the overall demand. During the winter period, the CHP is constantly providing electricity. However, during the summer period the electricity production is intermittent, as the heat demand is low and the highest heat production comes from other sources such as thermal solar systems.

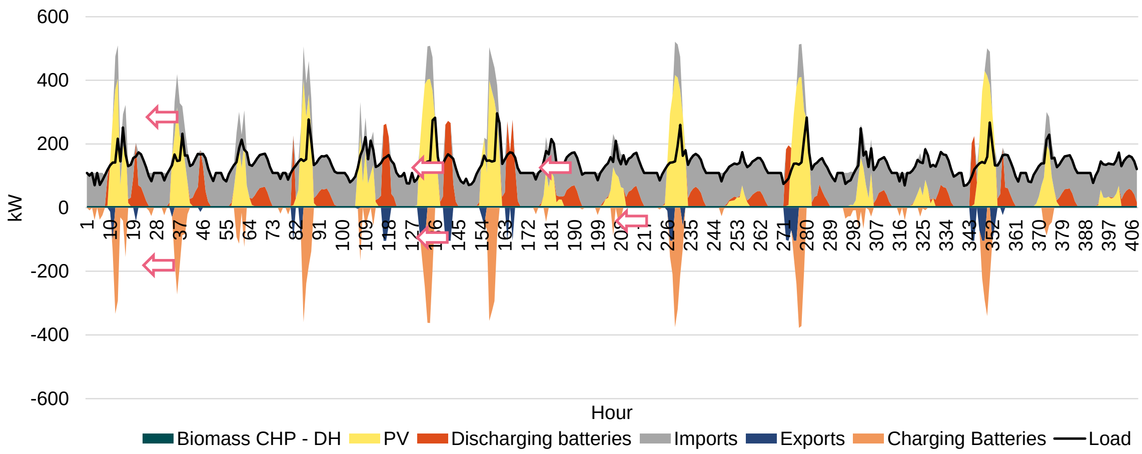

Figure 134: Hourly electricity production by technologies in the last two weeks of January according to the BK-SC in the village of Ispaster in 2030

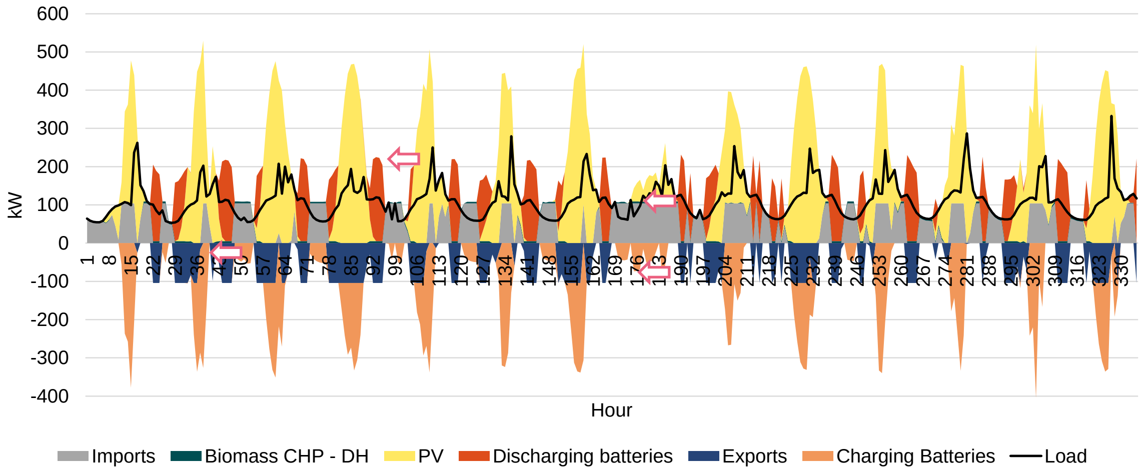

Figure 135: Hourly electricity production by technologies in the first two weeks of July according to the BK-SC in the village of Ispaster in 2030

HEATING SECTOR

Figure 136 shows the annual heat supply in the BK-SC per week by the different heat production technologies in 2030. As for the Ref-SC, the heat is produced and consumed locally in the village of Ispaster, not allowing trading with an external network out the community. Heating sector in the BK-SC performs like in the Ref-SC, since no fundamental changes were assumed. In this sense, the total heat production is estimated as 1,450 MWh (including 15% distribution losses) on annual basis and **the DH is the main heat source** with 1,102 MWh. In the DH system, biomass CHP and the biomass-powered boiler have equal shares of around 39% of this total heat production, and geothermal HPs contribute with 189 MWh.

Among the single systems, LPG-driven boilers are the main source providing 175 MWh followed by air-source HPs, with 124 MWh. The overall heat production for solar thermal panels is 72 MWh, of which 53 MWh are allocated in the DH. Aligned to this, heat storage can balance 24 MWh of heat load, where 21 MWh takes place for the DH system.

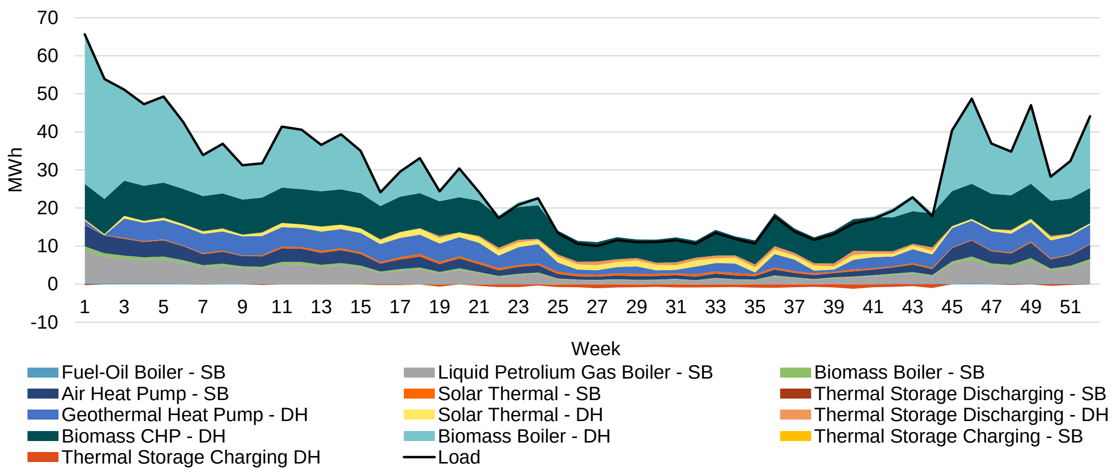

Figure 136: Annual heat production by technologies according to BK-SC in Ispaster in 2030

Figure 137 and Figure 138 illustrate hourly heat production profiles for the last two weeks of January and July, representing the winter and summer periods, respectively. Like in the Ref-SC, during the winter period the thermal storage is in operation only few hours due the low solar radiation. It is during the summer period where heat storage systems are more active, being able to store the surplus heat from the solar panels and switch this to another period. In fact, **in the DH system, the heat surplus from the CHP system is stored to use this heat when solar production is not enough to cover the demand** in its production periods. During summer period, the geothermal HPs in the DH are in operation only when the electricity prices are low, while the CHP plant produces heat mainly during moments of high electricity prices.

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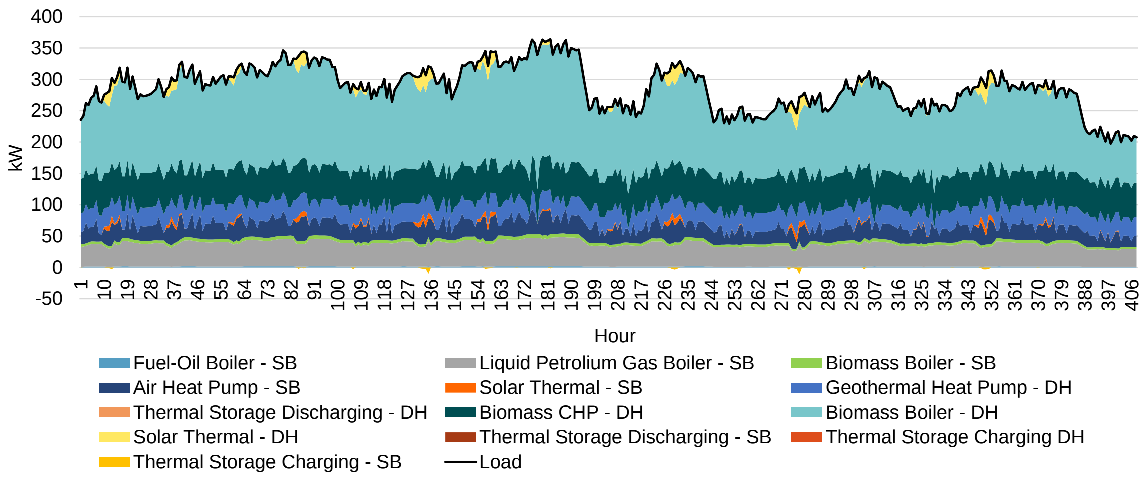

Figure 137: Hourly heat production by technologies in the last two weeks of January according to the BK-SC in the village of Ispaster in 2030

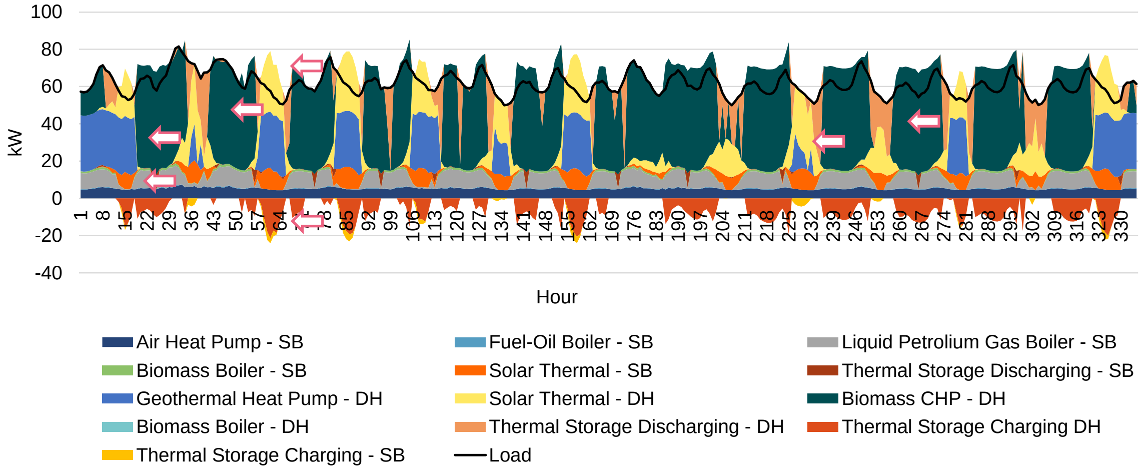

Figure 138: Hourly heat production by technologies in the first two weeks of July according to the BK-SC in the village of Ispaster in 2030

CO_2 EMMISSIONS

Figure 139 shows the direct and indirect CO_2 emissions by sector of the BK-SC scenario in Ispaster, which are similar than for the Ref-SC. The only difference is a reduction of the indirect CO_2 emissions due to the lower dependence from the main grid. Total CO_2 emissions account for 419 tons of CO_2 of which 15 are indirect. In the calculation of indirect CO_2 emissions in 2030, an emission intensity of electricity production of 60 tons CO_2 /MWh is considered based on the Spanish NECP (European Commission, 2022). There is a 49% reduction in the overall CO_2 emissions compared to the base year due to the expansion of local PV and the DH driven by renewable energy sources. The high reduction of intensity of the electricity production in the national grid also has a high effect in the reduction of indirect CO_2 emissions. The transport sector is the main emitting sector with overall direct CO_2 emissions of 357 tons of CO_2, or 85% of the overall CO_2 emissions under this scenario.

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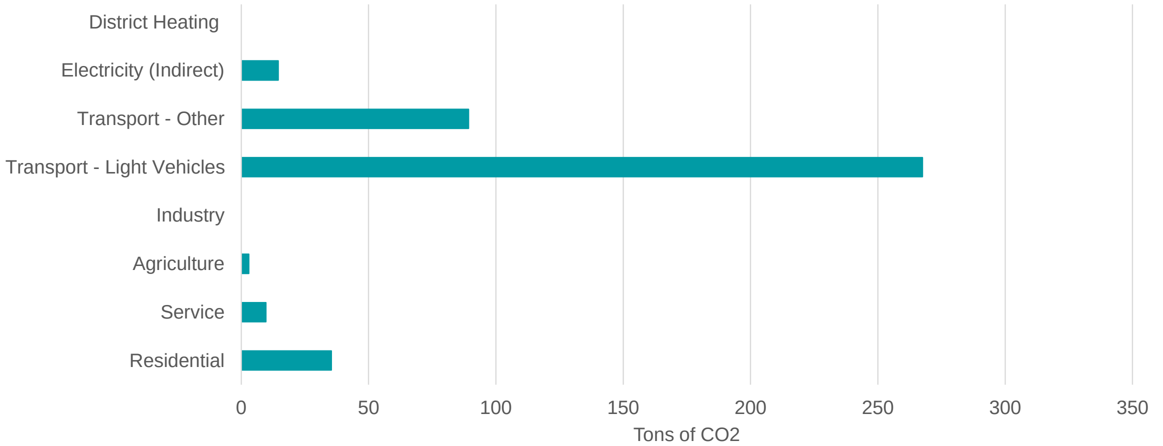

Figure 139: CO_2 emissions by sector of BK-SC scenario in the village of Ispaster

5.5.3. EI-SC

This scenario explores the full independence of Ispaster from the national grid. Figure 140 shows the overall local heat and electricity production, and the transmission line capacity in this scenario. **PV panels capacity experiences an increase lower than for the BK-SC**, accounting for 534 kWp, **due to the CHP systems considered in this case, with a higher biomass CHP ratio**. Electric battery capacity grows to 1,068 MWh to balance the electricity needs, being the highest among the three scenarios. The DH capacity increases up to 918 kW, but there are substantial changes in its configuration with respect to the Ref-SC. **In the EI-SC, the CHP plant has a main role** with 540 kW of thermal capacity. The capacity of the biomass boiler for the DH also grows, reaching 336 kW or 31% more compared to the Ref-SC. Despite the DH capacity increase, **solar thermal panel capacity remains the same, while geothermal HPs are not necessary** at all. For individual systems in buildings, **HPs and solar thermal panels are the only technologies** available, with solar thermal capacity being the same as for the Ref-SC and air-source HPs growing to 116 kW.

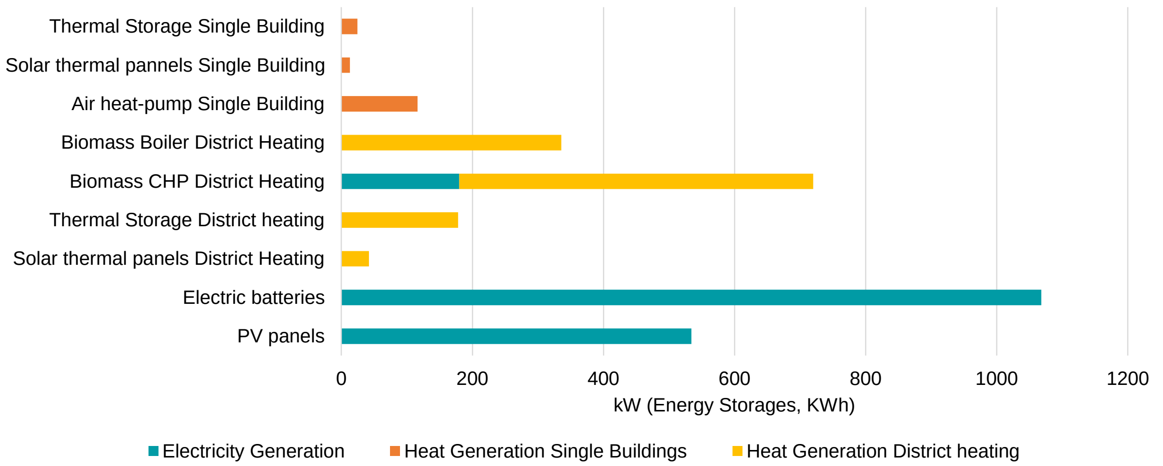

Figure 140: Local energy production capacity and transmission line capacity for EI-SC in Ispaster in 2030

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ELECTRICITY SECTOR

Figure 141 shows the annual electricity demand of the EI-SC by different type of end-use technologies per week in 2030. This electric load follows the EI-Ref load projection. In this context, the total annual electricity demand for the EI-SC is estimated at 1,428 MWh (including 3% of electricity distribution losses), 46% more compared to the Ref-SC and the BK-SC. This high increase is a result of the full electrification of light vehicles in transport sector representing 549 MWh of electricity, as well as of a minor increase of air-source HPs in single building with 94 MWh. In this context, **appliances are still the main electricity consumers** with 783 MWh, however its share in the total energy consumption is reduced to 55%. The flexibility measure DSM has a minor impact, by switching 4 MWh of the space heating demand, despite the increase of air-source HP capacity. Finally, electricity balance provided by electric batteries achieves 187 MWh, around 7% less than Ref-SC.

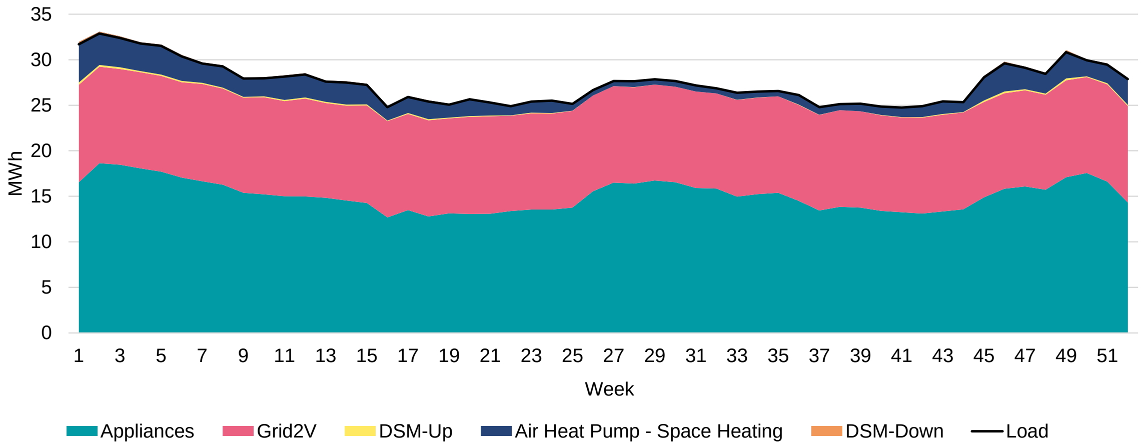

Figure 141: Annual electricity demand by end-use technologies according to EI-SC in the village of Ispaster in 2030

Figure 142 and Figure 143 illustrate hourly electricity demand profiles for the village of Ispaster for the last two weeks of January and the first two weeks of July in 2030, illustrating winter and summer periods, respectively. Both figures show that, **due to the larger number of EVs, the saw-tooth patterns are more pronounced** representing up to 88% of the overall electricity demand in some timescales. The impact of DSM is low to modify the overall electricity profile, despite the higher capacity of air-source HPs in the system.

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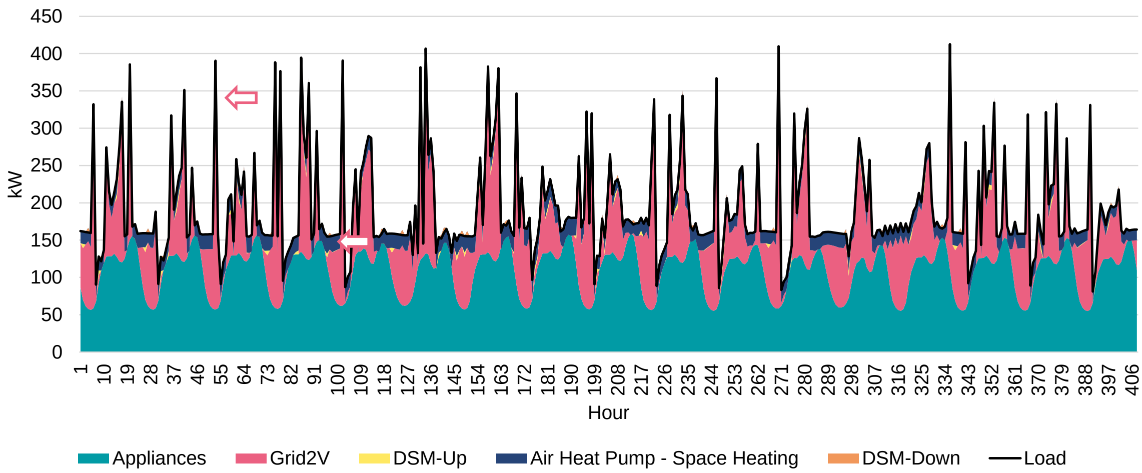

Figure 142: Hourly electricity demand in the last two weeks of January for the EI-SC in Ispaster in 2030

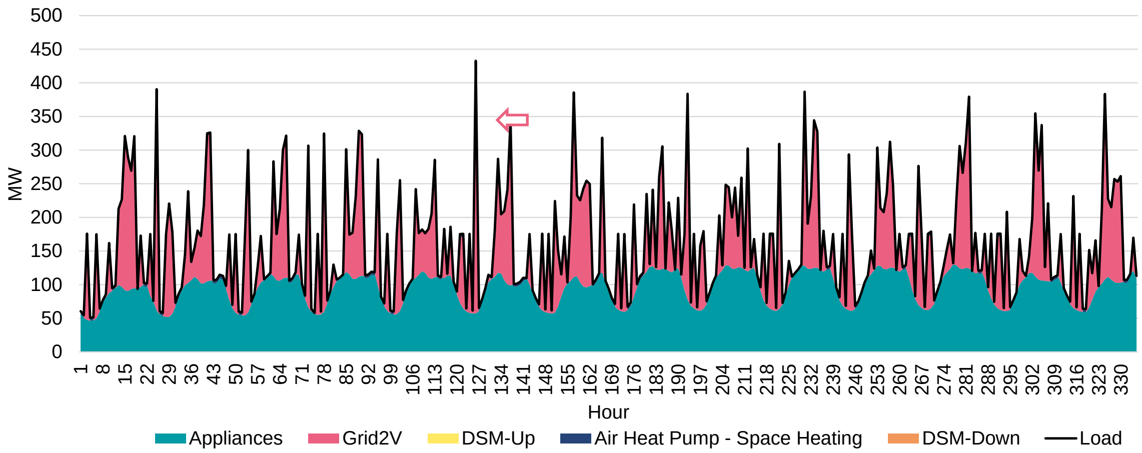

Figure 143: Hourly electricity demand in the first two weeks of July for the EI-SC in Ispaster in 2030

Figure 144 shows the annual electricity supply of the EI-SC from local sources, as well as the charging and discharging of batteries required to cover the electricity supply per week in 2030. Positive values are electricity from the sources that is used to cover the electricity demand, meanwhile the negative one represents the electricity that it is stored in batteries. The annual locally-generated electricity accounts for 1,471 MWh (including transmission losses), of which the CHP system has the main production with 817 MWh; 56% of the total electricity production. The remaining part is covered by PV panels. **The CHP system is the main technology during the winter period**, covering in some weeks around 90% of the electricity demand during this period. During the summer periods, due to the increase of solar irradiation, the CHP electricity drops, covering around 30% of electricity demand during some weeks of this period. Finally, the use of fix electric batteries, i.e. the ones not integrated into EVs, allows balancing 187 MWh on an annual basis; 7% less compared to Ref-SC.

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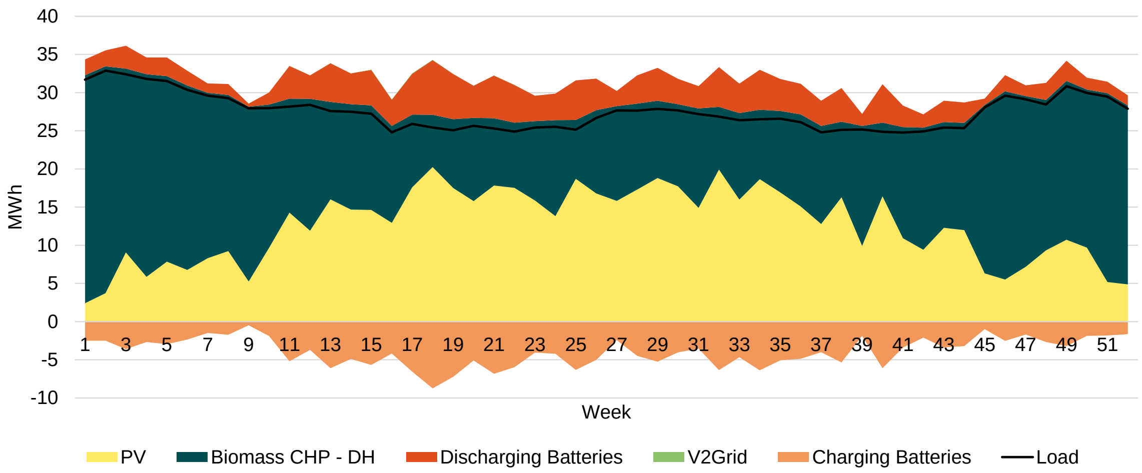

Figure 144: Annual electric supply by technologies according to the EI-SC in Ispaster in 2030

Figure 145 and Figure 146 illustrate hourly electricity production and supply profiles for the last two weeks of January and the first two weeks of July, illustrating winter and summer periods, respectively. Both figures show how the electricity production surplus from PV panels can be stored in batteries to be consumed in another time. **During the winter period the CHP system works as a baseload system being the predominant electricity source**. However, during the summer period, the electricity production from the CHP is intermittent due to the lower heat demand. However, the higher production of the electricity from PV panels can easily interact with the electric batteries to cover the demand.

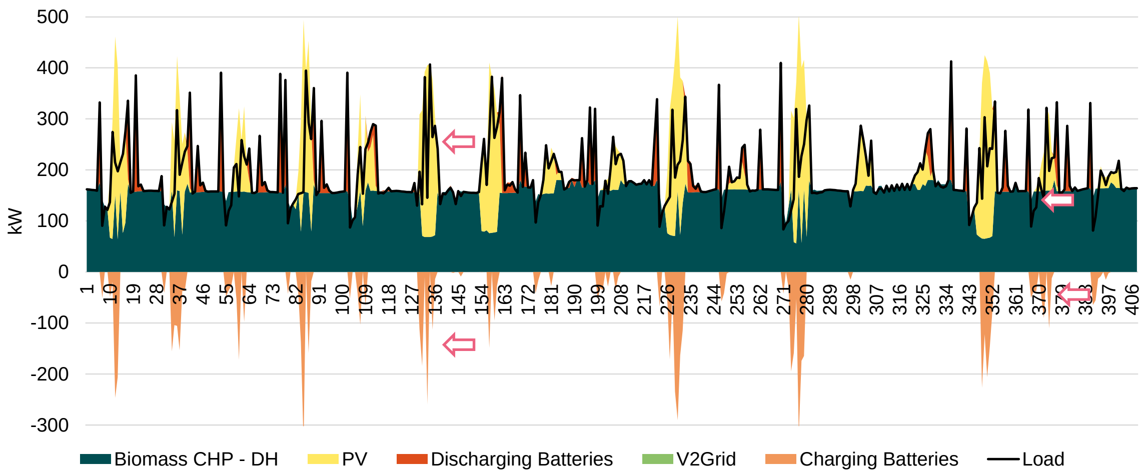

Figure 145: Hourly electricity production by technologies in the last two weeks of January according to the EI-SC in the village of Ispaster in 2030

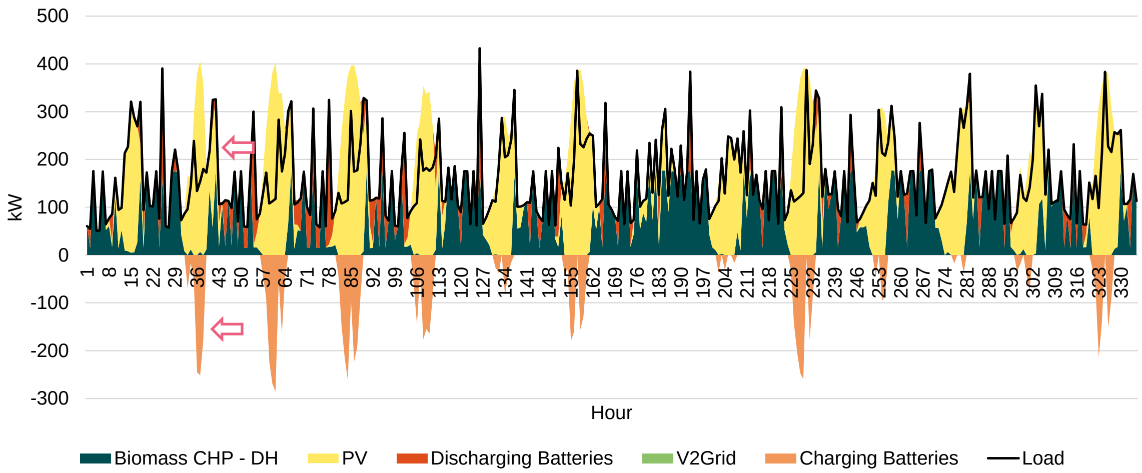

Figure 146: Hourly electricity production in the first two weeks of July for the EI-SC in Ispaster in 2030

HEATING SECTOR

Figure 147 shows the annual heat supply of the EI-SC per week by the different technologies in 2030. In Ispaster, as for previous scenarios, heat is produced and consumed locally, hence heat trade with an external network out of the community is not possible. As in the Ref-SC, total annual heat production is estimated at 1,450 MWh (including 15% distribution losses) and **the DH is the main heat source** with 1,102 MWh. The biomass CHP is the main heating system producing 947 MWh of heat followed by the biomass boiler with 105 MWh, representing 86% and 10% of the total heat production in the DH, respectively. During the first week of the year, the biomass boiler is the main technology for heat production in the DH system. This is because in this period the CHP system must also supply electricity, promoting the electricity production in detriment of the heat production. The remaining part of heat is covered by the solar thermal panels linked to the DH. **Air-source HPs constitute the main technology for single systems**, generating 347 MWh of heat, 94% of the total in this category, being the remaining part covered by the solar thermal panels. Heat storage systems can balance 24 MWh of heat load, where 21 MWh are for the DH.

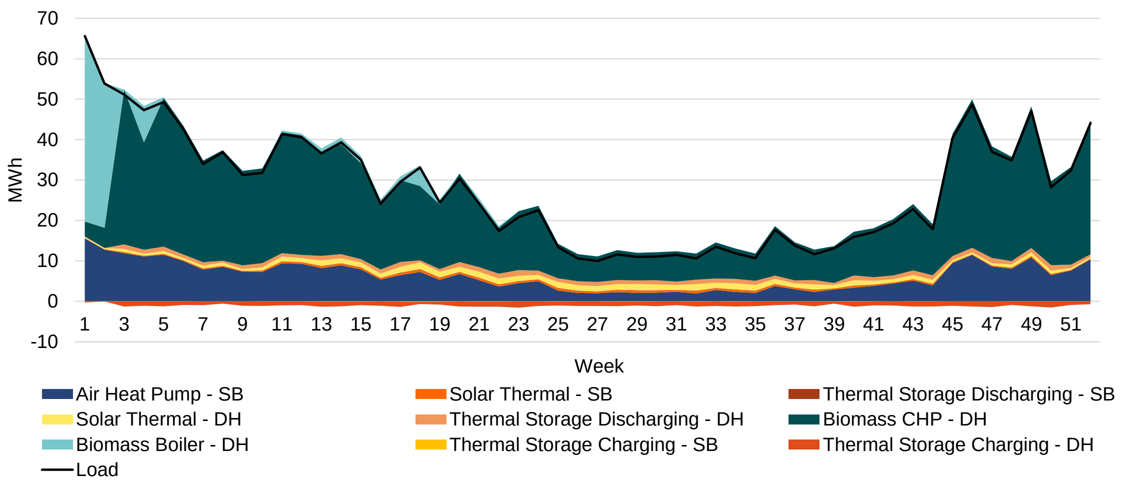

Figure 147: Annual heat production by technology according to EI-SC in Ispaster in 2030

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Figure 148 and Figure 149 illustrate hourly heat production profiles representatively for the last two weeks of January and July in 2030, respectively. Both scenarios show **a surplus of heat production by the CHP system that is stored and switched to cover future demand**. This effect is very pronounced, producing a saw-tooth profile because of the double functionality of this technology, thus providing heat and electricity. When the electricity requirements for this technology are lower, it generates more heat to be used later or vice-versa. This allows this technology a more efficient and cost-effective operation.

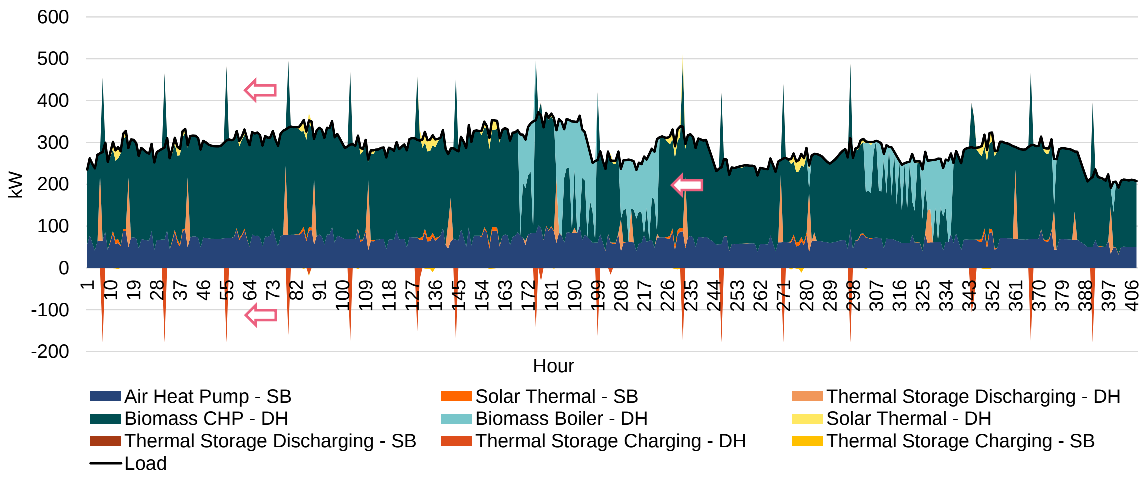

Figure 148: Hourly heat production by technologies in the last two weeks of January according to EI-SC in the village of Ispaster in 2030

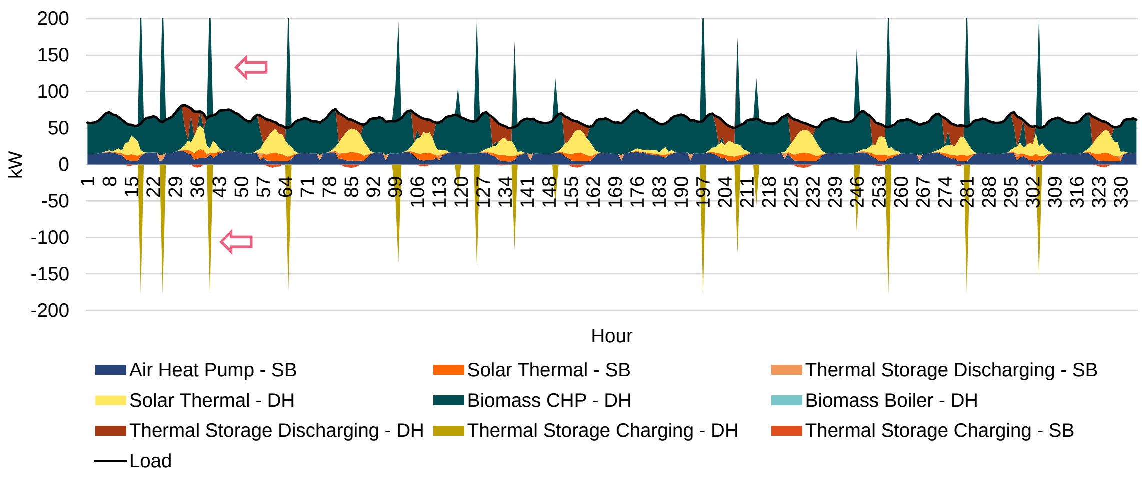

Figure 149: Hourly heat production by technologies in the first two weeks of July according to EI-SC in the village of Ispaster in 2030

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CO_2 EMMISSIONS

In the EI-SC scenario the full decarbonization of the village of Ispaster is achieved. This is due to the high changes in the energy demand and supply. On the demand side, the changes are focussed on the replacement of all fossil fuel boilers in the residential and service sectors by HPs, the use of biofuels in the agriculture sector, as well as a full penetration of EVs and the use of bio-diesel for other transport modes. On the supply side, the main changes are the full disconnection from the national grid and the fully use of renewable energy sources for heating and electricity production.

5.6. Comparison of Scenarios

5.6.1. Electric sector

Figure 150 shows the comparison of the capacity of the local electricity production sources and the transmission line of the different scenarios and the base year in the village of Ispaster. For all the assessed scenarios PV capacity experiences a high increase, as well as the batteries to balance the electric system. The use of CHP plants in all the assessed scenarios is relevant. However, while the Ref-SC and the BK-SC scenarios are supported by a CHP system with a 5-kW electrical capacity, the installed capacity of this technology grows in the EI-SC scenario to allow the village to be fully disconnected from the national energy grid. The BK-SC scenario has the largest PV capacity expansion with 647 kWp and also needs 880 kWh of capacity of electric batteries for black-out prevention. However, PV panels capacity has a lower increase in the EI-SC scenario compared to the BK-SC scenario, accounting for 534 kWp. This reduction can be explained due to the CHP systems considered in this simulation, with a capacity of 180 kW.

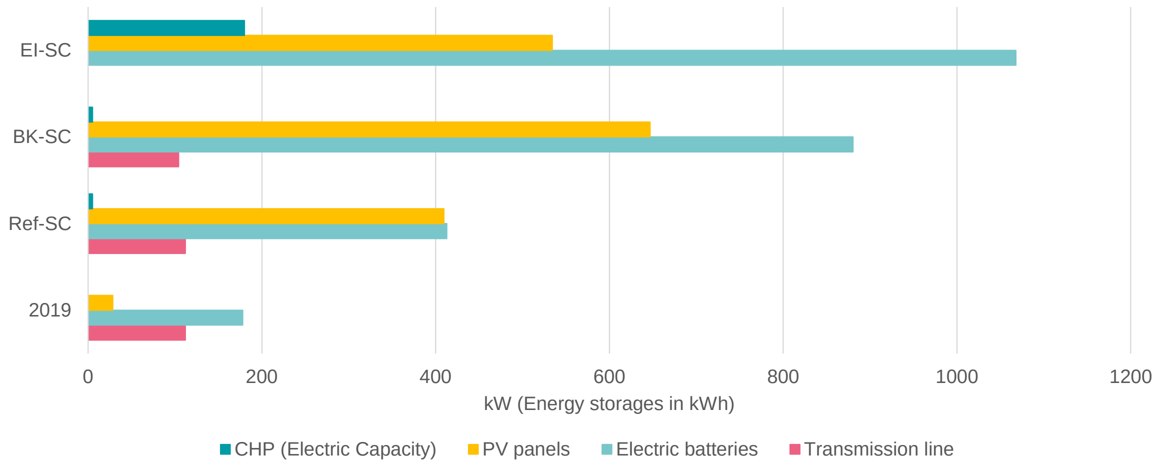

Figure 150: Comparison of the electric capacity of the local electric production sources and the transmission line of the scenarios and base year in the village of Ispaster

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Figure 151 shows the comparison of the electricity demand, production, imports and exports of the scenarios and the base year in the village of Ispaster. The electric load is the same in the Ref-SC and the BK-SC scenario. The total annual electricity demand for both scenarios is estimated at 981 MWh. However, in the BK-SC scenario additional electric power capacity is needed to cover the demand during the simulated black-out event. For the EI-SC scenario, the capacity grows due to the highest electrification of the heating sector and light vehicles up to 1,428 MWh, 46% more compared to the other scenarios.

In the Ref-SC scenario, the annual generated electricity in the village of Ispaster is 564 MWh, 58% of the total electricity demand. PV panels constitute the main producer with a production of 525 MWh, o 93% of the total electricity production. The CHP system is responsible for the production of the remaining part. In the BK-SC scenario, the local production increases up to 807 MWh, equivalent to 82% of the total electricity demand, and PV panels remain as the main producer with 768 MWh taking 95% share in the total electricity production. Annual electricity imports decrease slightly compared to the Ref-SC scenario. However, the exports grow down to 268 MWh due to the possibility of a higher electricity production from PV. Finally, in the EI-SC scenario the annual locally electricity production accounts for 1,471 MWh. However, in this case, the CHP system is the main producer with 817 MWh, 56% of the total electricity production. As in this scenario the village of Ispaster performs as an energy island there are no electricity imports or exports.

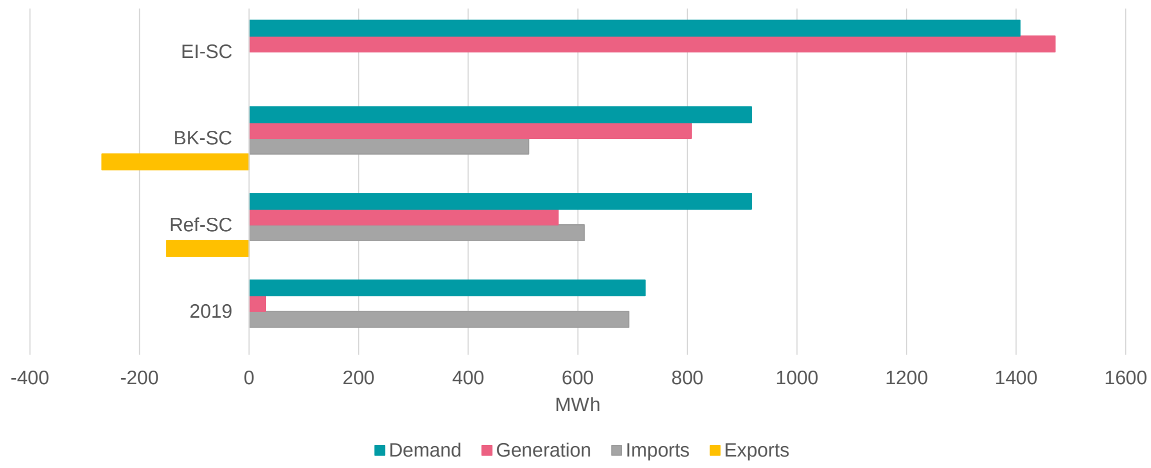

Figure 151: Comparison of the electricity demand, production, imports and exports of the scenarios and the base year in the village of Ispaster

5.6.2. Heating sector

Figure 152 shows the comparison of the heating capacity by technology of the scenarios and the base year in the village of Ispaster. For all the assessed scenarios, there is a high transformation in the heating sector due to the growth of DH in the village. The Ref-SC and the BK-SC scenarios perform in a similar way. However, the DH capacity in the Ref-SC accounts for 382 kW, while in the BK-SC scenario reaches 408 kW. In both scenarios, biomass boilers constitute the main technology and the local DH network is supported by a ground-source HP and a biomass CHP system with 55

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kW of thermal capacity. Moreover, the most significant development of thermal storage takes place mainly in the DH to allow balancing heat production due to the inclusion of the CHP system. In these two scenarios, individual heating systems connected to buildings account for a total capacity of 128 kW, of which 50% are driven by fossil fuels. The EI-SC scenario is the one with the highest differences. In this scenario, DH capacity increases up to 918 kW. However, the CHP plant has a main role with 540 kW of thermal capacity. The biomass boiler for DH also experiences an expansion, while geothermal HPs are not necessary at all. For individual systems in buildings, fossil fuel boilers are phased out.

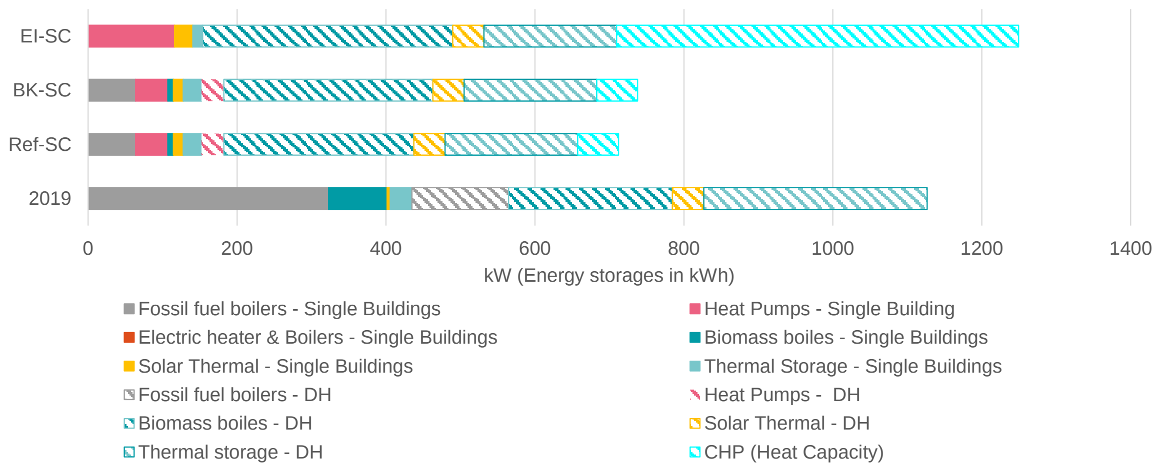

Figure 152: Comparison of the heating capacity by technology of the scenarios and base year in the village of Ispaster

Figure 153 shows the comparison of the heat production by technology of the scenarios and the base year in the village of Ispaster. For all the assessed scenarios, the total heat production is estimated at 1,450 MWh on annual basis, and DH is the main heat source with 1,102 MWh. In the Ref-SC and the BK-SC scenarios, the biomass CHP and the biomass boiler share equally around 39% of the total heat production of the DH, and geothermal HPs contribute with 189 MWh. Among the individual systems in buildings, LPG boilers are the main source providing 175 MWh, followed by air-source HPs with 124 MWh. It is in the EI-SC scenario where biomass CHP achieves the dominant preponderance in the DH system producing 947 MWh, 86% of the total heat production in the DH. Within the individual systems, air-source HPs constitute the main technology, generating 347 MWh of heat or 94% of the total in this category, being the remaining part covered by the solar thermal panels.

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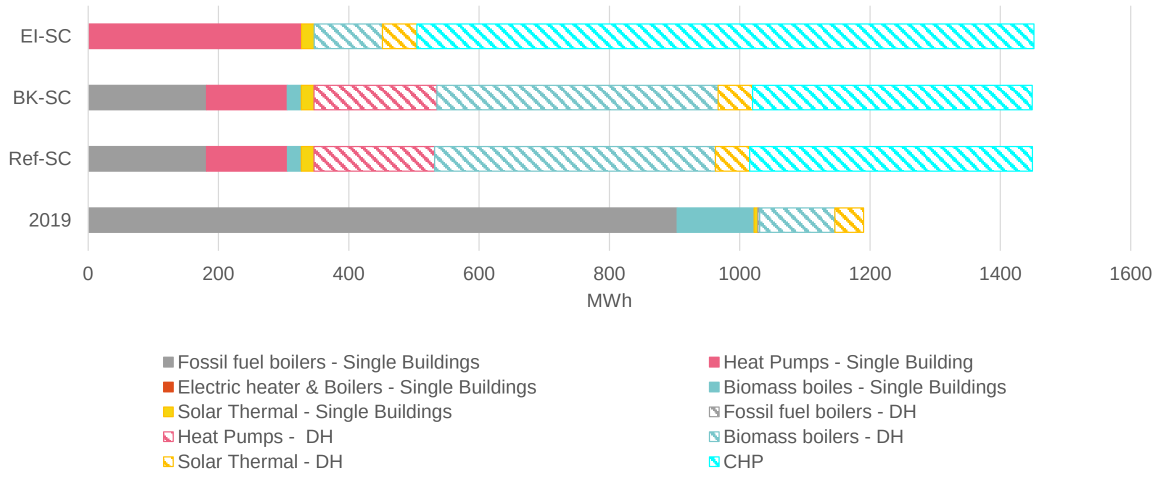

Figure 153: Comparison of the heat production by technology of the scenarios and base year in the village of Ispaster

5.6.3. Transport sector

Figure 154 presents the comparison of the energy consumption in the transport sector of the scenarios and the base year in the village of Ispaster. There is a reduction of the fuel consumption for all the assessed scenarios compared to the base year due to the penetration of EVs with higher efficiency than ICE vehicles. The Ref-SC and the BK-SC scenarios perform equally with an overall energy consumption of 1,465 MWh, around 5% less compared to the base year. In the EI-SC scenario, due to the massive inclusion of EVs the highest energy reductions occur, accounting for 888 MWh that implies a 42% reduction compared to base year.

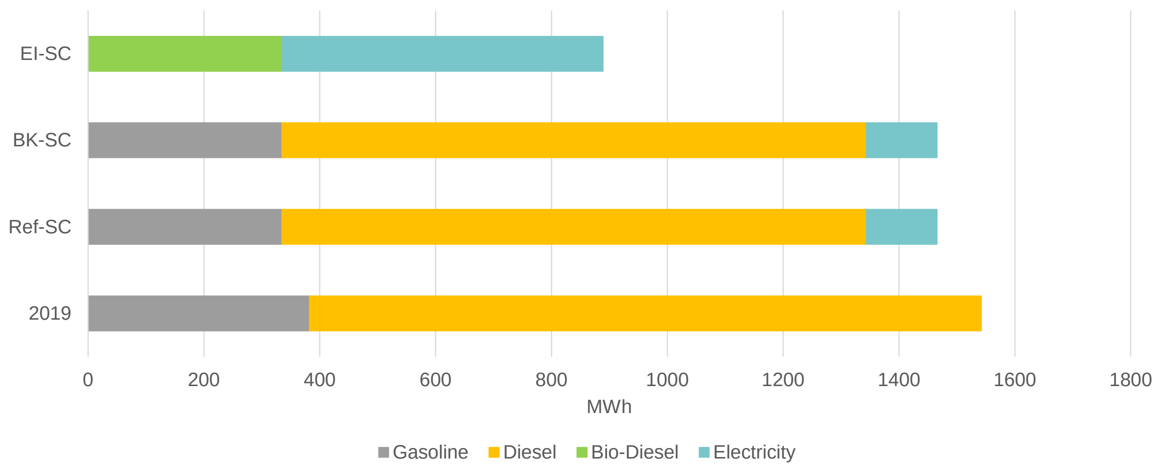

Figure 154: Comparison of the energy consumption of the scenarios and base year in Ispaster

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5.6.4. Decarbonization

Figure 155 shows the comparison of the CO_2 emissions by sector of the scenarios and the base year in the village of Ispaster. In all the assessed scenarios there is a clear reduction of the overall CO_2 emissions compared to the base year, achieving a full decarbonization in the EI-SC scenario. The BK-SC scenario performs in a similar way than the Ref-SC scenario, being the only difference a reduction of the indirect CO_2 emission due to the lower dependence from the national grid. The Ref-SC and the BK-SC scenarios have a reduction of 47% and 49% in the overall CO_2 emissions compared to the base year, respectively. This is due to the expansion of the local PV as well as the DH driven by renewable energy sources. The high reduction of the intensity of electricity production in the national grid also has a high contribution in the reduction of the indirect CO_2 emissions. In the EI-SC scenario the full decarbonization of the village is achieved. This is due to the full replacement of fossil fuels by biofuels and the electrification of the light vehicles, and to a lesser extent due to the use of HPs in combination with the full disconnection from the national grid and the use renewable energy sources for heating and electricity production.

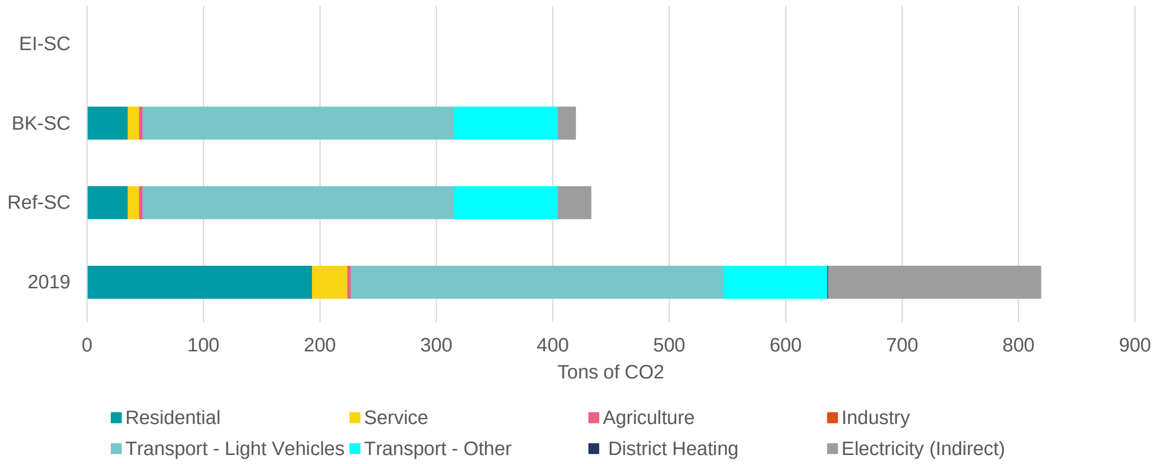

Figure 155: Comparison of the CO_2 emissions by sector of the scenarios and base year in Ispaster

5.7. Conclusions

Three scenarios are investigated under the LocalRES project for the village of Ispaster: Reference Scenario (Ref-SC), Blackout Scenario (BK-SC) and Energy island Scenario (EI-SC). The goal of these scenarios is to define in the long-term perspective (2030) different possibilities about how a hypothetical energy community constituting the whole village can perform and can support decarbonization of the village.

The overall conclusion is that electricity production from **PV panels , the biomass-driven CHP as well as the use of electric batteries can support the electrification of the village of Ispaster**. Furthermore, **these technologies can contribute in blackout prevention and reduce the dependence from the national grid**.

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DSM has a minor impact to modify the overall electricity profile due to the low penetration of air-source HPs. The expansion of EVs can produce a saw-tooth effect in the overall electricity profile, and **smart-charging can support to reducing the dependence from the grid**.

The scenarios show, that the heating sector has a high transformation due to the growth of the DH in the village, limiting the expansion of single building technologies including air-source HPs. This implies a limited expansion of the electricity consumption for space heating. In this regard, **EVs are the main driver of the rise in the future electricity demand**. **The dominant technology in the expansion of the DH will be biomass boilers** followed by the biomass CHP system and geothermal HPs. In addition, solar thermal systems can play a supporting role, especially in the summer period. **PV panels will be the main technology for electricity production**, which leads to a high dependence from the electricity imports during the winter period, when the solar radiation is lower.

To prevent the village of Ispaster against blackout events, the residual load approach (BK-SC) implies that **there is need for an additional increase of PV panel capacity as well as electric batteries**. However, this supplementary capacity of electric batteries allows to increase the electricity balance and a more effective exchange with the national grid. Moreover, flexibility measures such as electric batteries together with smart charging of EVs can reduce 7% the needs of the effective capacity of the transmission line from the current 112 kW to 104 kW.

Full independence from the national grid to work as an energy island, together with the increase of the electricity demand due to full electrification of light transport sector and single building heating technologies (EI-SC) **makes key the biomass CHP systems**. However, this technology must have high biomass CHP ratio to be able to cover the new electricity needs. Electricity production will be dominated by the CHP system especially during the winter period, but this relevance is switched to PV panels during summer period. In this context, **energy storage takes a fundamental role to balance both electricity and heat**

In terms of decarbonization, in all the assessed scenarios there is a clear reduction of the overall CO_2 emissions compared to the base year, achieving a full decarbonization in the EI-SC scenario. The BK-SC scenario performs in a similar way than the Ref-SC scenario, being the only difference a reduction of the indirect CO_2 emission. The Ref-SC and Ye BK-SC scenarios have a reduction of 47% and 49% in the overall CO_2 emissions compared with the base year, respectively. This is due to the expansion of local PV as well as the DH driven by renewable energy sources. In the EI-SC scenario the fully decarbonization of the village is achieved. This is due to the full replacement of fossil fuels by biofuels and the electrification of the light vehicles, in combination with the full disconnection from the national grid and the use renewable energy sources for heating and electricity production.

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6/ Ollersdorf demo case

6.1. Overall pilot description

The village of Ollersdorf is located in the South-East of Austria in the district of Güssing (State of Burgenland), see Figure 156. The village has about 935 inhabitants (Statistik Austria, 2022a) with a rural-oriented economy, small industries, and commercial business.

Figure 156: View of the village of Ollersdorf.

The village is part of the Klima und Energie Model Region (KEM) "KEM Golf und Thermenregion Stegersbach" which is a program of the Austrian Climate and Energy Fund (BMK, 2022). Ollersdorf is also part of the Innovation Lab act4.energy, an initiative of the Austrian Ministry of Transportation, Innovation and Technology in the program "City of Tomorrow" (Energie Kompass, 2022).

In 2019, around 20% of the households were equipped with PV installations, and the overall installed PV capacity was around 317kWp. There is a battery storage in the townhall that supplies electricity to the town hall, a doctor's office and the fire station in case of a blackout. A carport with integrated PV and 5 EV charging stations is also available. While several efforts are made in the electric sector to develop the transition towards renewables, heating sector still relies on fossil fuels, with oil- and gas-fuelled heating systems being very common.

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6.2. Current energy characterization of the pilot – Base Year 2019

6.2.1. Annual energy assessment demand

Figure 157 shows the breakdown of the overall final energy demand by fuel and sector in the village of Ollersdorf, which is estimated at around 26,196 MWh (without electricity distribution losses). The available data are limited, and it is assumed that the village performs in the same way as the Thermenregion Stegersbach region of which the Municipality of Ollersdorf is part (Energie Kompass, 2019) to fill the data gaps.

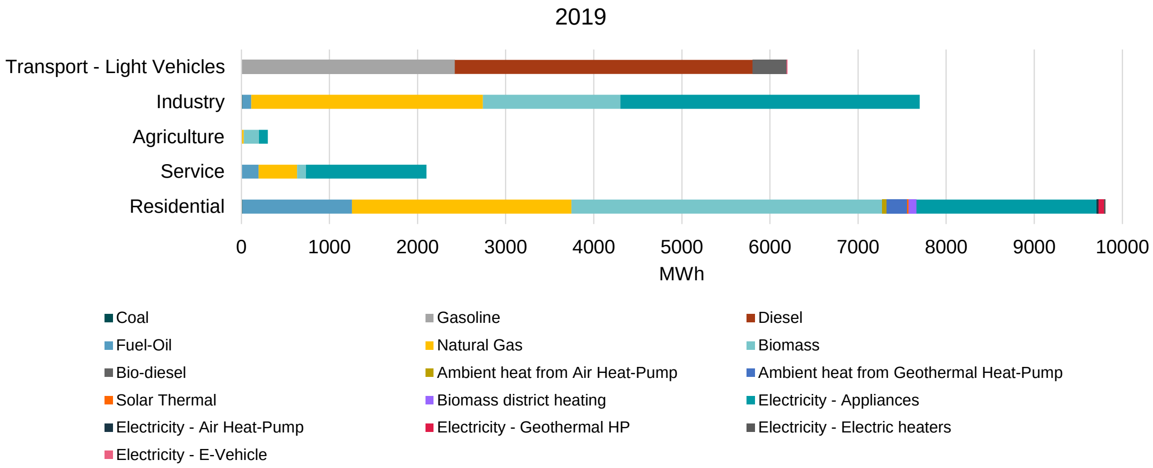

Figure 157: Energy demand by fuel and sector in 2019 in the village of Ollersdorf

The residential sector is the main energy consumer with an annual energy consumption of 9,809 MWh, that represents 38% of the total energy consumption. In this sector, **biomass and natural gas are the main fuels** accounting for 3,528 MWh and 2,490 MWh, respectively. Electricity consumption is 2,147 MWh used almost completely by appliances, as the electricity for heating purposes accounts 97 MWh. The service sector accounts 2,100 MWh, where electricity consumption represents 65% of the energy needs. Electricity is only used in appliances, and natural gas is the main fuel for heat production with a fuel consumption of 438 MWh, followed by fuel-oil with 194 MWh. The transport sector accounts for 6,200 MWh of fuel demand. This sector is dominated by fossil fuels, where diesel and gasoline represent 55% and 39% of the fuel needs, respectively. The remaining part is covered by blended biodiesel. **The industrial sector is the second largest consumer** with an average energy consumption of 7,700 MWh. Electricity consumption is the main fuel accounting 3,399 MWh, 44% of the total fuel needs. Natural gas and biomass are the main heating sources with 2,630 MWh and 1,560 MWh, respectively. Finally, the agriculture sector is the smallest one in terms of energy demand, with a fuel consumption of 300 MWh.

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CO_2 EMMISSIONS

Figure 158 shows the direct and indirect CO_2 emission by sector of the base year in the village of Ollersdorf. The total CO_2 emissions accounts for 3,748 tons of CO_2 of which 669 tons of CO_2 are indirect emissions due to the electricity consumption from the national grid. The remaining are direct emissions from the different sectors. In the calculation of the indirect CO_2 emissions an emission intensity of electricity production 100 tons of CO_2 by MWh is considered, which is the average value for Austria in the period 2017-2019 (EEA, 2022). This is done to avoid possible fluctuations for 2019 and capture better the current trend. Direct CO_2 emissions from transport and residential sectors are the main CO_2 emission source, accounting for 1,537 tons of CO_2 and 837 tons of CO_2, respectively. Both sectors represent around 63% of the overall CO_2 emission in the village of Ollersdorf.

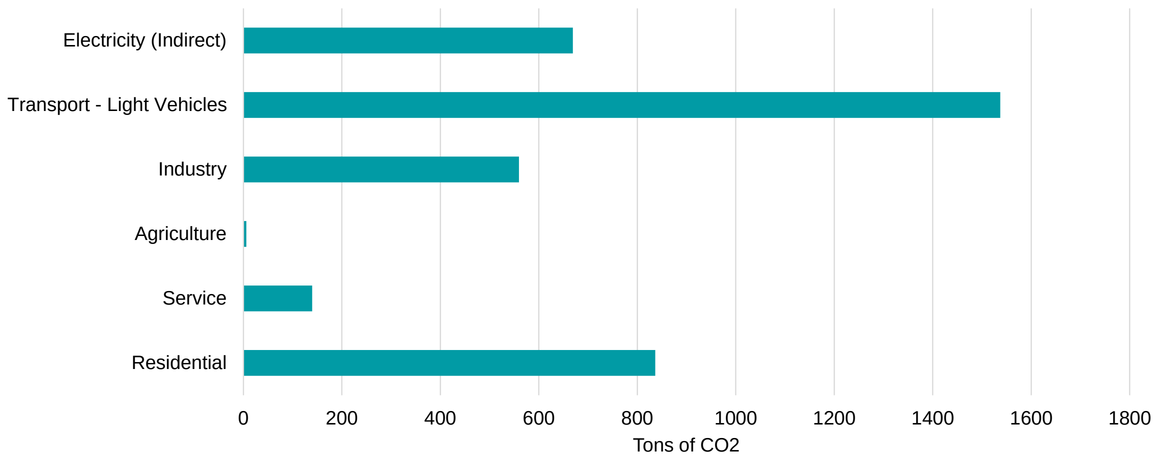

Figure 158: CO_2 emissions by sector of the base year in the village of Ollersdorf

ELECTRICITY DEMAND PROFILE

Figure 159 presents the estimated hourly electricity demand profile in the village of Ollersdorf. The total annual electricity consumption accounted for 7,025 MWh in 2019. The profile is based on the electricity consumption from measured data of 15 single houses located in the village. The system monitors the electricity consumption in each single house every 15 minutes. Therefore, the first step to build the electricity profile for the village of Ollersdorf is aggregating the data to adopt a resolution of 1 hour, which is the one used by the Balmorel tool. Second, the profiles are filtered removing the ones that have gaps in the monitoring data or have high discrepancies. Finally, the remaining data are averaged to get the electricity profile of the village.

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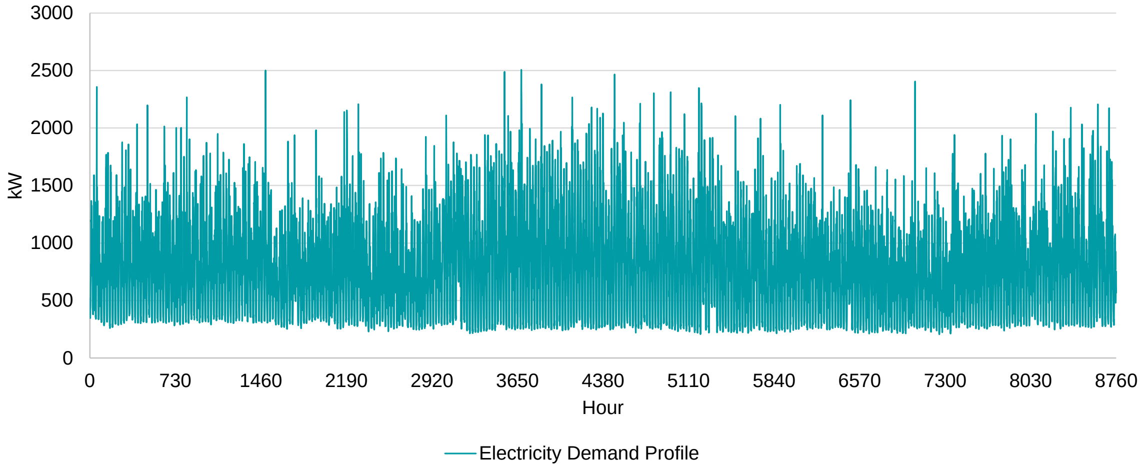

Figure 159: Electricity demand profile for the village of Ollersdorf

HEAT DEMAND PROFILE – SPACE HEATING AND DHW

The estimated hourly heat demand profile of Ollersdorf is shown in Figure 160. The annual total heat demand corresponded to a total of 7,605 MWh in 2019. There is not information about the hourly heat load profile of Ollersdorf. Therefore, **a synthetic profile was built based on combination of two independent profiles**, one that represents space heating and another one that represents DHW. **The profile for space heating was generated from the combination of the monthly HDD profile** based on the meteorological data of the closest weather station in the village of Kleinzicken (BizEE, 2022) and the hourly temperature profile for the village from PVGIS (JRC-European Commission, 2022). **The DHW profile follows the general DHW hourly resolution profile developed within the European REACT project** (REACT project, 2018). Finally, both profiles are normalized, weighted, and summed up to estimate the overall hourly heat demand profile. It is estimated that the space heating consumes 96% of the total heat demand, while DHW represents 4% according to the energy consumption data for buildings in Thermenregion Stegersbach region, of which the Municipality of Ollersdorf is part (Energie Kompass, 2019).

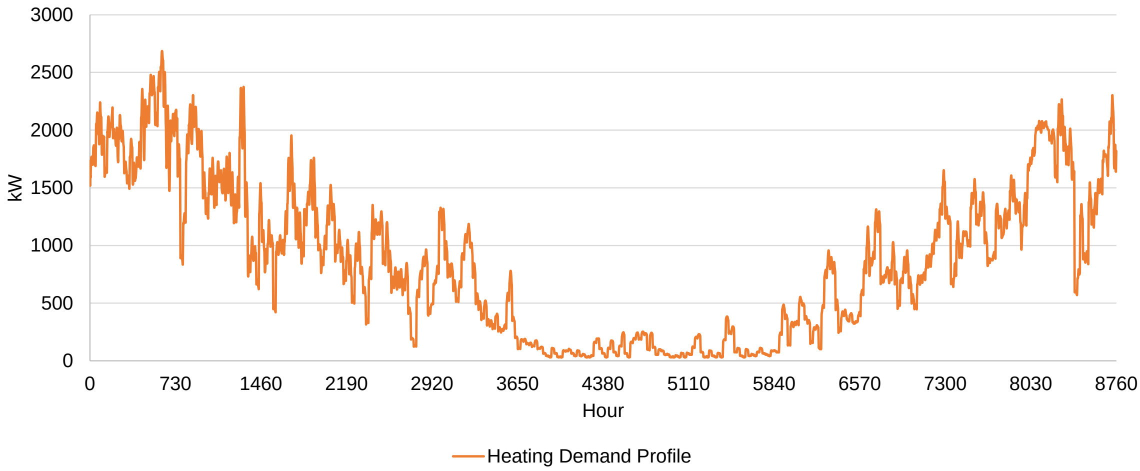

Figure 160: Estimated heat demand profile for the village of Ollersdorf

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6.2.2. Local heat and electricity production capacity

Figure 161 shows the local heat and electricity production as well as the transmission line capacity in the village of Ollersdorf in 2019. In this year, **the village of Ollersdorf accounted for a total installed PV capacity of 317 kWp**, that generates 332 MWh of electricity with 1050 FLH (full-load hours). **PV panels are connected to electric batteries with an overall capacity of 38 kWh**. The transmission line that connects the village to the national grid have an effective capacity of 5 MW, enough to cover the winter and summer peaks. **In the heating sector, biomass boilers constitute the most relevant technology** with around 1,29 MW of installed capacity, followed by natural gas boiler with an installed capacity of 1,04 MW. Solar thermal panels play a minor role with an installed heat capacity of 18 kW, and they are supported by thermal storage systems with a capacity of 53 kWh. Finally, other technologies such as coal boilers or electric boilers have a marginal role.

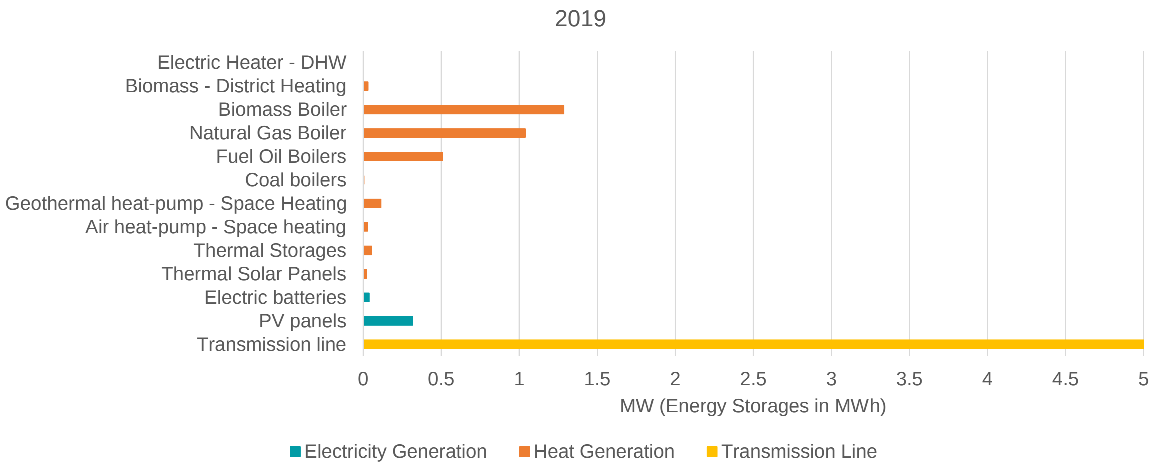

Figure 161: Local heat and electricity production capacity and electricity transmission line capacity for the village of Ollersdorf

ELECTRICITY PRICES PROFILE

The electricity prices profile for Austria in 2030 is presented in Figure 162. **The electricity prices for Austria in 2030 are based on the EU28-Balmorel model**. It is expected that Austrian electricity prices will have a high fluctuation due to the increase of vRES connected to the national grid, with an average electricity price around 43.3 €/MWh in 2030. In this context, Austria electricity prices, as well as the local the transmission line capacity, that connects the village of Ollersdorf to the national grid, determine how the community interacts with its national market; more precisely, how exchange (import/export electricity) takes place under a least-cost solution framework.

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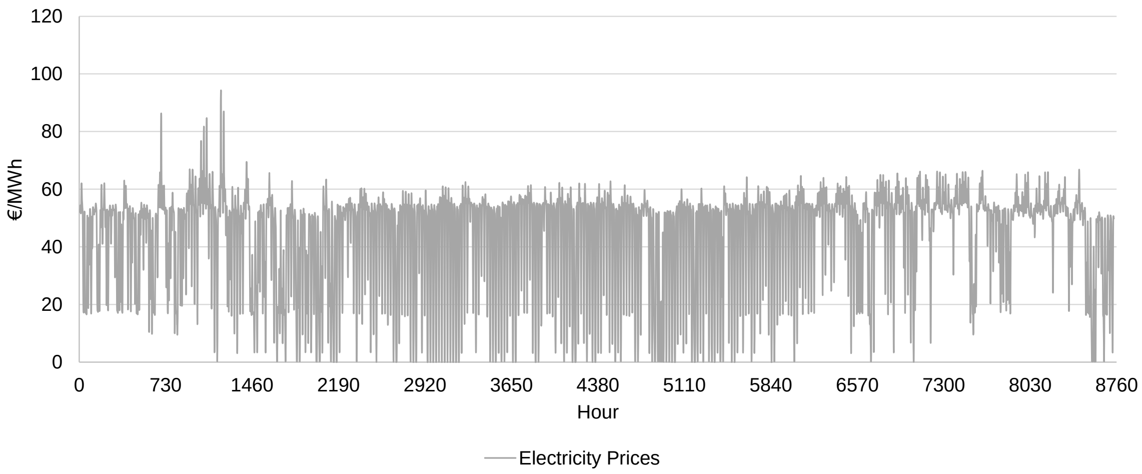

Figure 162: Estimated electricity prices profile for Austria in 2030

SOLAR PROFILE

Figure 163 shows the hourly electricity production profile for PV panels in the village of Ollersdorf. This profile is the **average hourly profile from the data collected from 27 PV installations located in the village** in 2019. This PV profile is also used to define thermal energy production from solar thermal panels.

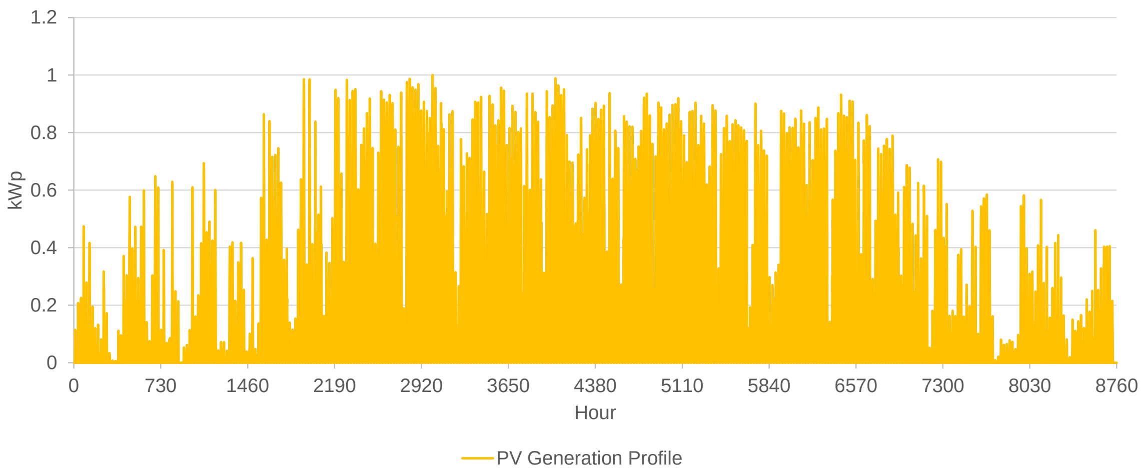

Figure 163: Electricity production profile for PV panels in Ollersdorf (normalized to 1 kWp)

WIND PROFILE

Figure 164 shows the hourly electricity production profile for wind turbines in of Ollersdorf. This **wind profile was built using COSMOS-REA6 software** (Uni. Bonn, 2022) taking the wind speed data in the area of the village from the representative year of 2008 in combination with a Vestas turbine model V136 (Vestas, 2022) which is able to deliver high and efficient energy production in low- and medium-wind conditions. Currently, there are not wind turbines in the village; however, the full-load hours parameter for these systems is estimated in 1,340 FLH in the area of the village.

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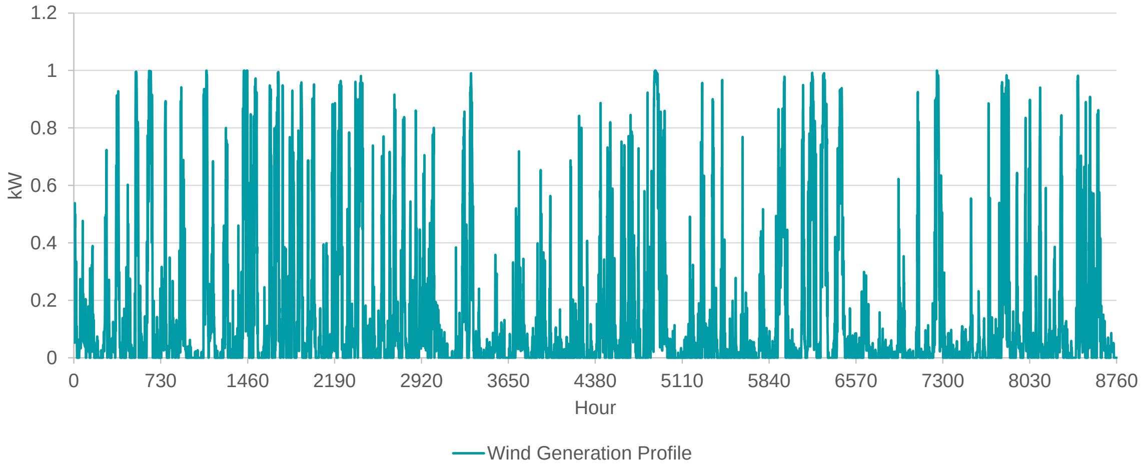

Figure 164: Electricity production profile for wind turbine in Ollersdorf (normalized to 1 kW)

REFUELLING PROFILE OF THE HYDROGEN-BUSES (H_2-BUSES)

The village of Ollersdorf is exploring the possibility of **replacing the current school buses powered by diesel by new ones powered by hydrogen**. Moreover, the electrolyser to generate the hydrogen to refuel the H_2-buses should be located into the village. In this context, the hydrogen consumption for H_2-buses is estimated in around 28 MWh. In this calculation, **it is assumed that two H_2-buses are used and two routes are done by each bus every school day** with an average length by route of 34 km and with an average consumption of 1.1 kWh/km (Hanhee et al., 2021). Figure 165 shows the designed annual hydrogen charging profile for the H_2-buses. It is considered that **charging time takes place at 6:00 and 11:00 during school days** before starting the route to bring or pick up the students to or from the school. During the holiday periods (Christmas, summertime, Easter, Spring week and Autumn week) the buses are stopped and no refuelling is necessary.

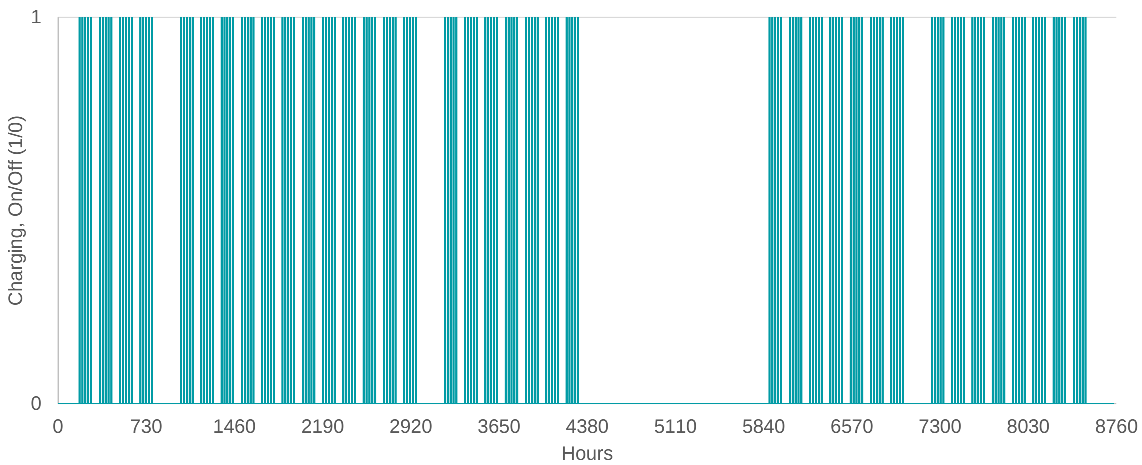

Figure 165: Designed annual hydrogen charging profile for the H_2-buses in Ollersdorf

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OTHER ASSUMPTIONS CONCERNING THE TRANSPORT SECTOR

There are two EVs in the village of Ollersdorf and therefore, **the transport sector is dominated by diesel- and gasoline-fuelled vehicles** accounting around 263 and 361 of light vehicles in 2019. Considering the energy consumption for transport sector and the number of light vehicles, the average annual vehicle-kilometre (vkm) is estimated in around 19,616 vkm in the village.

6.3. Scenario definition

Three scenarios are analysed within the LocalRES project for the village of Ollersdorf. The goal of these scenarios is to define the least-cost solutions for different possibilities in the long-term perspective (2030) about how the establishment of a hypothetical energy community including all the village can perform and support the energy decarbonization of Ollersdorf. In this analysis, the impact of flexibility measures such as DSM, smart charging for EVs, energy storage, HPs as well as the use of PV panels and hydrogen production is explored. As for the rest of demo sites, these scenarios were built together with local stakeholders to reflect their view about how the energy transformation in the pilot could be.

- ***Reference Scenario (Ref-SC):*** In this scenario, the village concentrates their efforts to **increase local vRES capacities to achieve electricity balance** (local electricity production equals to electricity demand). The capacity increase is aligned with the Austrian NECP (European Commission, 2022). **Flexibility measure such as smart charging for EVs, DSM and energy storage (batteries and thermal energy storage) are considered.**
- ***Blackout Scenario (BK-SC):*** In this scenario, the village keeps their efforts to increase local vRES capacities to achieve electricity balance. In addition, the **replacement of all fossil fuel heaters by HPs as well as of light vehicles to EVs** is explored. The replacement of fossil fuels by biomass in the industrial and agriculture sector are also set. In addition, it is explored **how flexibility measures and local resources can support the mitigation of blackout events**. The black-event duration was considered 1 hour to be conservative, as these events have a lower duration.
- ***Hydrogen in Transportation Scenario (H2T-SC):*** This scenario considers all the main aspects included in the EB-SC, but it goes a step further to **decarbonize the transport sector**. In this sense, diesel-driven **school buses are replaced by H_2-buses**. Moreover, this new infrastructure must be in the village.

Table 6 summarizes the technical description for the island of Ollersdorf's scenarios. For all the scenarios the maximum capacity for PV is estimated in 8.7 MW and no limitations in the wind capacity installation are considered. In the Ref-SC there are not additional effort in the electrification of the heating and transport sectors. However, this situation has a radical change in the BK-SC and the H2T-SC by the full replacement of fossil fuel boilers by electric HPs and light vehicles by EVs with smart charging to be able to charge the batteries according to the local condition of grid and electricity prices. Furthermore, in both scenarios the electric system in Ollersdorf must limit the impact of blackout events of one-hour duration. The H2T-SC goes further in the decarbonization of transport sector by replacing the current school buses by two H_2-buses. Hydrogen infrastructure, such as the electrolyser, must be in the village and powered by local vRES. For all the scenarios, the effective capacity of the transmission line that connects the village to the national grid is 5 MW.

Table 6: Scenario characteristics in the village of Ollersdorf in 2030

	Ref-SC	BK-SC	H2T-SC
Max. allowed PV	Up to 8.7 MW	Up to 8.7 MW	Up to 8.7 MW
Max. allowed wind	Up to obtain Energy Balance	Up to obtain Energy Balance	Up to obtain Energy Balance
Max. allowed electric batteries	No restrictions	No restrictions	No restrictions
Heat pumps	No changes	Replace 100% of fossil fuel heating boilers	Replace 100% of fossil fuel heating boilers
Fossil fuels in Agriculture and Industrial sectors	No changes	Replace 100% of fossil fuels by biomass	Replace 100% of fossil fuels by biomass
DSM	Available	Available	Available
Allowed thermal solar	No change	No change	No change
E-vehicles	No change	100% of vehicles	100% of vehicles
Type of e-charge	Smart charging	Smart charging	Smart charging
H_2-Buses	N/A	N/A	2 school buses
Transmission capacity to national grid	5 MW	5 MW	5 MW
Blackout event	N/A.	1 hour	1 hour

6.4. Demand projection for the scenarios

Several drivers and assumptions are required to establish and estimate the future energy demand forecast of the village of Ollersdorf by 2030.

The residential sector is the largest energy consumer sector. The drivers to estimate the future domestic hot water and electricity demand are based on population forecasting, while space heating demand is linked to the refurbishment rate of buildings. **It is expected that the population in the village of Ollersdorf will increase** following the current trend of Burgenland region where is place the village (Statistik Austria, 2022b). This implies that the population increases

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around 2.9% in 2030, moving from about 935 inhabitants to 962 inhabitants in 2030 (Statistik Austria, 2022a). Despite the number of buildings remain the same in 2030, **the impact of the refurbishment in buildings will reduce the heat demand for space heating**. This refurbishment rate is assumed based on the set target consisting of increasing the average annual building renovation rate to 3% annually between 2020 and 2030 (IEA, 2020), which means around 7% reduction of current heat demand considering that a refurbishment building consumes 19% less heat that an standard one (Surecity Project, 2019).

In the service sector, it is assumed that future energy demand services are driven by the population forecast. This is characterized by small local businesses in the village of Ollersdorf, such as groceries or bakeries, whose level of activity depends on the local population available.

The future energy demand for the transport sector also follows population´s forecast. The annual vehicle-kilometre (vkm), with an average of 1.2 passenger per vehicle, remains the identical. Additionally, at least 14 EVs are expected to be available in 2030 according to the scenarios for the development of electric mobility in Austria (Pötscher, 2015). Finally**, the energy demand in the industry and agriculture sectors remain the same**, as no changes are expected in the future of these sectors.

Accordingly, two future energy demand scenarios named DMD-Ref and DMD-ELC for the different energy sectors are estimated for 2030. These scenarios are built by combining the drivers to estimate future demand together with the specific needs of the sectors. Furthermore, they consider scenario specifications as well as the impact of switching to more efficient technologies.

Figure 166 shows the DMD-Ref demand scenario, which is considered in the Ref-SC, that follows the expected future trend without incentivising the replacement of fossil fuel technologies in the transport and heating sectors.

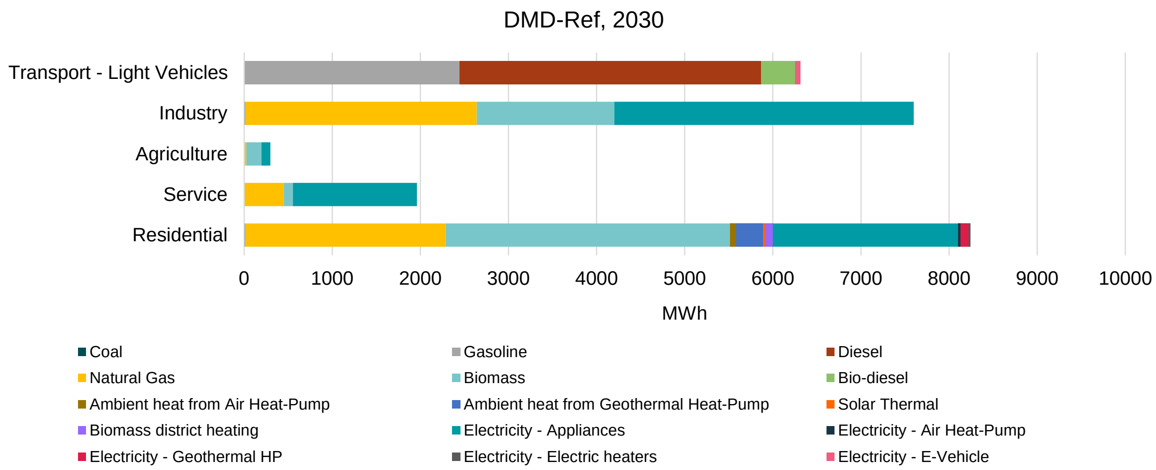

Figure 166: DMD-Ref demand scenario in the village of Ollersdorf in 2030

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The DMD-Ref scenario considers an overall fuel demand of 25,851 MWh in 2030 (without distribution losses) that represent 1% reduction of the energy consumption compared to 2019. This is due to the **increase of the energy consumption which is compensated by the refurbishment of buildings and light expansion of EVs**.

The residential sector remains as the largest energy sector with a total fuel consumption of 9,377 MWh, representing a 4% reduction compared to 2019. **Biomass is still the main energy source** with 3,227 MWh of fuel consumption followed by natural gas with 2,277 MWh. The electricity consumption, still focussed on appliances, accounts for 2241 MWh; 4% more compared to 2019.

The services sector accounts for 2,161 MWh of fuel consumption in 2030, that represents a 3% increase compared to 2019 following population growth. Electricity is the main source with 1,408 MWh, 65% of the overall fuel needs. **For the heating sector, natural gas and fuel-oil are the most relevant fuels** with 451 MWh and 200 MWh, respectively.

There is also an **increase in fuel consumption in the transport sector** of around 2% compared 2017. As previously said, in 2030 14 EVs are expected to be in place with an electricity consumption of 59 MWh. However, this sector is still dominated by fossil fuels, where diesel and gasoline fuel consumption accounts for 3,415 MWh and 2,448 MWh, respectively. The remaining part is covered by blended biodiesel. Finally, the energy demand for industry and agriculture stays the same as in 2019.

Figure 167 represents the DMD-ELC demand scenario, which is considered in the BK-SC and in the H2T-SC. These scenarios include a complete replacement of heating boilers by HPs and ICE light-vehicles by EVs.

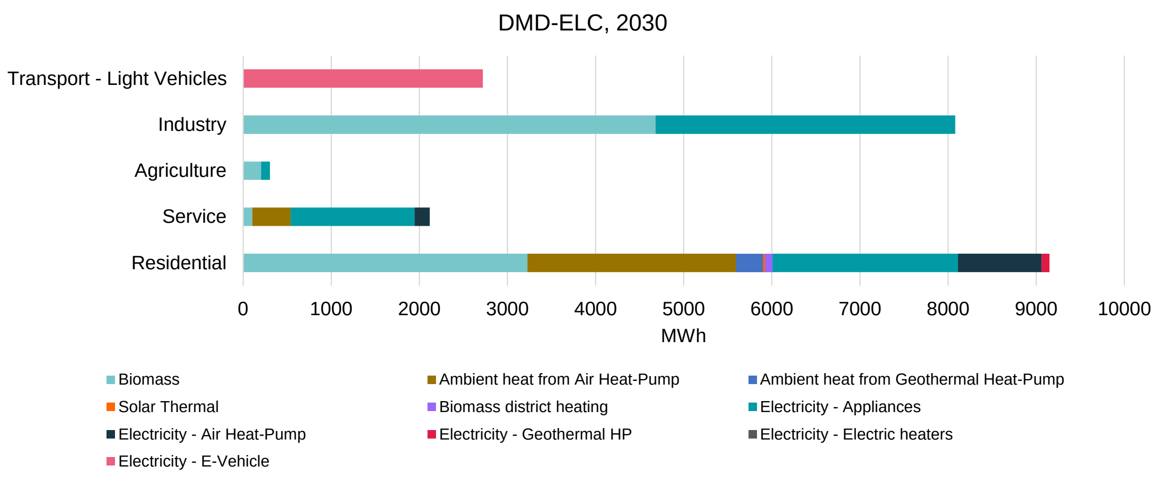

Figure 167: DMD-ELC demand scenario in the village of Ollersdorf in 2030

The DMD-ELC scenario implies an overall fuel demand of 22,370 MWh (without distribution losses) that represents 86% of the total energy demand compared to 2019. This happens mainly due to **the electrification of the transport sector for light vehicles that causes a reduction of 44% of**

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the energy demand in 2030. **Due to the electrification of the heating and transport sector, electricity demand grows** to 10,941 MWh representing 56% of the total energy demand. Biomass demand also rises, because the replacement of fossil fuels in the industrial and agriculture sector by this fuel. This implies biomass needs of 8,213 MWh in 2030, 53% more compared to 2019.

The residential sector remains the largest energy consumer sector with 9,147 MWh. This amount represents a decrease of 7% compared to 2019. **The replacement of fossil fuel boilers by HPs increases the electricity consumption** to 3,140 MWh, 46% more compared to 2019. Air-source HPs are the main contributor in the heating sector with 3,315 MWh of which 947 MWh is accounted for electricity, and the remaining energy comes from heat extraction from the ambient air. However, biomass remains as the second heat supplier with a contribution of 3,227 MWh.

The service sector accounts for 2,119 MWh of fuel consumption, which represents almost 1% more of the fuel demand compared to 2019. As in the residential sector, the replacement of fossil fuel boilers rises the electricity demand to 1,581 MWh, 75% of the overall fuel needs. The heating sector accounts for a fuel consumption of with 711 MWh, with air-source HP being the largest contributor with 604 MWh, of which 174 MWh is accounted for electricity and the remaining energy comes from heat extraction from the ambient air. The rest is covered by biomass.

In 2030, **100% of the light vehicles are expected to be EVs**, with an estimated electricity consumption of 2,720 MWh, **reducing by more than half the fuel needs** compared to 2019. This is due to the higher efficiency of EVs compared ICE-vehicles. The use of biodiesel in this sector disappears, as this fuel was blended with fossil fuels for transport. The hydrogen consumption of the H_2-buses in the H2T-SC is not included in Figure 66, and it is estimated in around 28 MWh.

Finally, the industry and agriculture sectors accounts 8,080 MWh and 304 MWh, respectively. This implies higher fuel needs compared to 2019. This is because these sectors **shift from natural gas and fuel-oil-based systems to biomass systems that have lower energy efficiencies**. The biomass needs for the industrial sector are 4,681 MWh, meanwhile for the agriculture sector are 203 MWh.

6.5. Results and Discussion

In this section, the simulation results of the Ref-SC, BK-SC and H2T-SC are presented. The results address how electricity and heating sectors in the village of Ollersdorf are covered by local energy resources and production technologies, as well by different flexibility measures such as storage power exchange (imports/exports) and DSM.

6.5.1. Ref-SC

Figure 168 shows the overall local heating and electricity production, and the transmission line capacity in the village of Ollersdorf for the Ref-SC. In this scenario, PV experiences a high increase with an installed capacity of 7.1 MWp to achieve an electric energy balance. This represents **an increase of PV capacity twenty-two times more compared to 2019**. In parallel, 121 kWh of

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electric batteries are required to balance the electric system. This value is relatively low compared to the PV capacity because the transmission line capacity of 5MW is high enough to allow a proper electricity exchange between the national grid and the village. **This large transmission capacity makes not necessary the use of batteries in a massive way as flexibility option** to balance the electric system. However, in this scenario the storage capacity of batteries is still around three times more compared to 2019.

In the heating sector, there are not relevant changes compared to 2019. **Biomass boilers are the main technology** with 1.2 MW followed by natural gas with1.1 MW and fuel-oil with 0.5 MW. The installed capacity of air-source HPs and ground-source HPs grows up to 38 kW and 151 kW, respectively. The remaining heating technologies play a minor role in the heating sector, including solar thermal panels and thermal storage as in 2019.

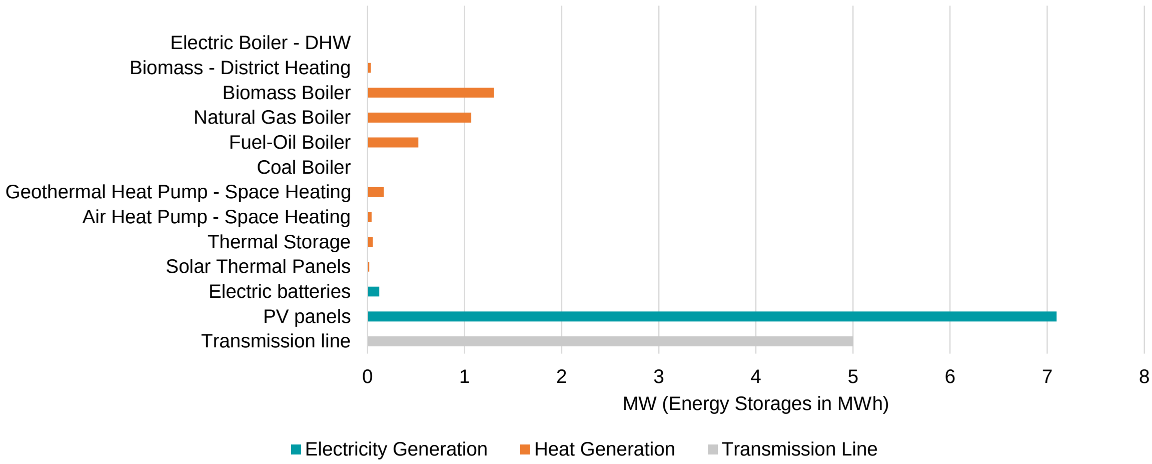

Figure 168: Installed local heat and electricity production capacities by technology and electricity transmission line capacity according to the Ref-SC in the village of Ollersdorf in 2030

ELECTRIC SECTOR

Figure 169 shows the annual electricity demand in the Ref-SC by different consumption technologies, as well as the impact of DSM per week in the village of Ollersdorf in 2030. The total electricity demand is estimated at 7,424 MWh (including 3% of electricity distribution losses) on an annual basis. **Electric appliances are the main electricity consumers** with 7,229, responsible for 97% of the total electricity demand. Electricity consumption for space heating (air-source HPs and geothermal HPs) accounts for 115 MWh of electricity concentrating this demand during wintertime. **DSM has a small contribution** shifting around 7 MWh of the electric demand for heating from HPs.

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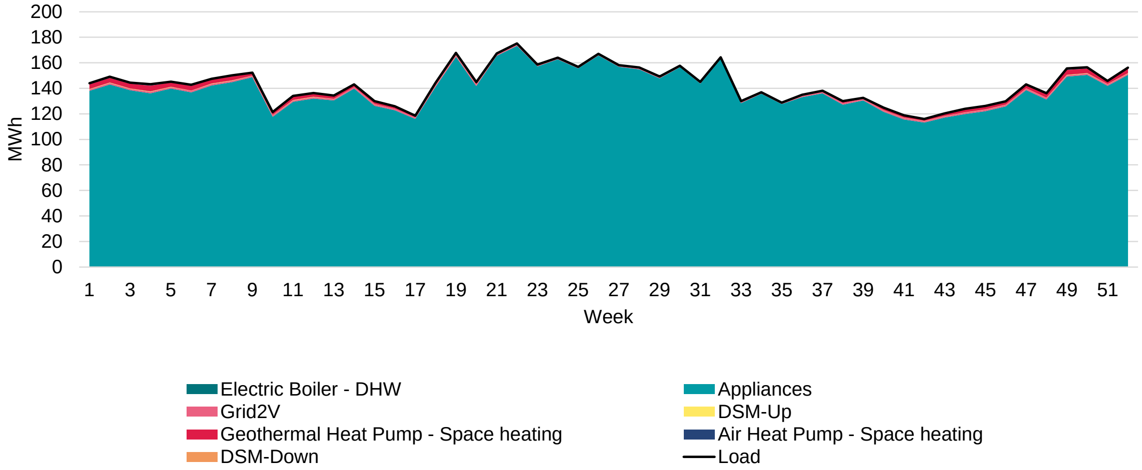

Figure 169: Annual electricity demand by technology according to the Ref-SC in the village of Ollersdorf in 2030

Figure 170 and Figure 171 illustrate hourly electricity demand profiles for the village of Ollersdorf for the two central weeks of December[8] and the first two weeks of July, illustrating winter and summer periods in 2030, respectively. Both figures show the **low impact of DSM and EVs on the modification of the overall electricity demand** profile. This is due to the low capacity of HPs which interact with the DSM, and the limited number of EVs under this scenario.

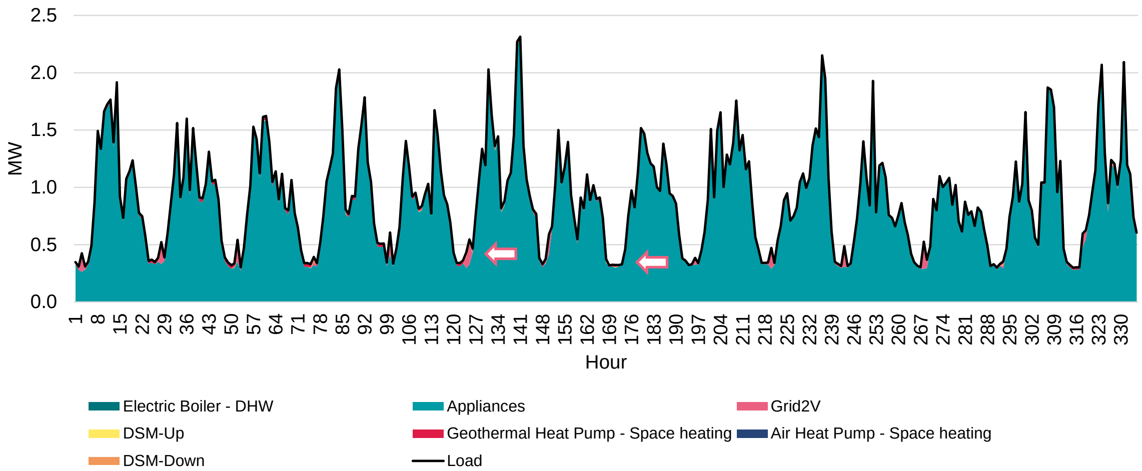

Figure 170: Hourly electricity demand in the two central weeks of December according to the Ref-SC in the village of Ollersdorf in 2030

8 The central two weeks (second and third week) of December (second and third week) are chosen as according to the BK-SC during this period the most critical blackout event can take place.

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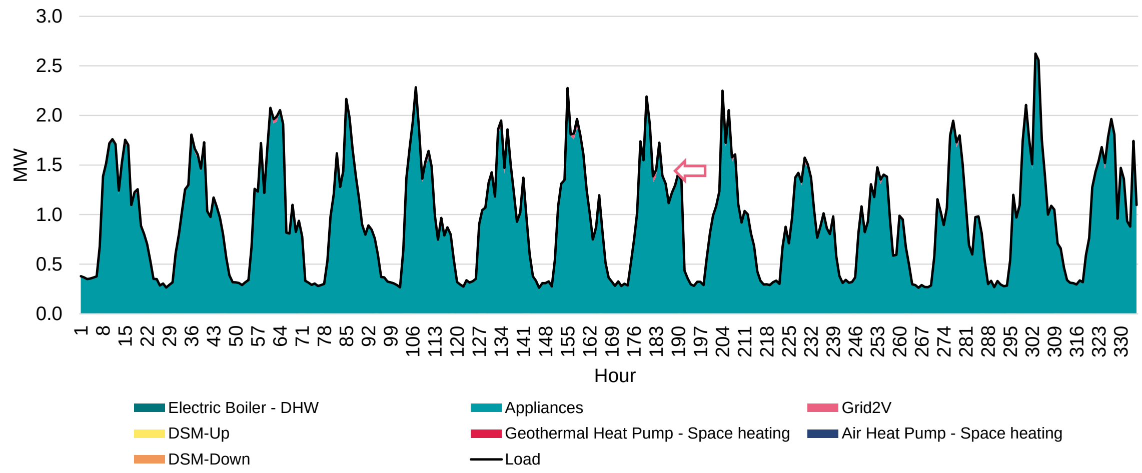

Figure 171: Hourly electricity demand in the first two weeks of July according to the Ref-SC in the village of Ollersdorf in 2030

Figure 172 shows the annual electricity supply per week in the Ref-SC from local sources, imports and exports, as well as the charging and discharging of batteries to balance the electricity system in 2030. Positive values are electricity supply of different options to meet the electricity demand, whereas the negative values represent the electricity that is either stored in batteries or exported. The annual locally-generated electricity in the village of Ollersdorf is 7,431 MWh, the same as the electricity demand (including transmission losses). **The local production only includes PV**, and electric batteries can balance 34 MWh. **Electricity imports are 3,758 MWh, the same as the electricity exports**. The transmission line of 5 MW has enough capacity to allow the electricity trading without bottlenecks between the village and the national grid, being the largest importing and exporting needs capacity in the transmission line of 2.3 MW and 4.6 MW, respectively.

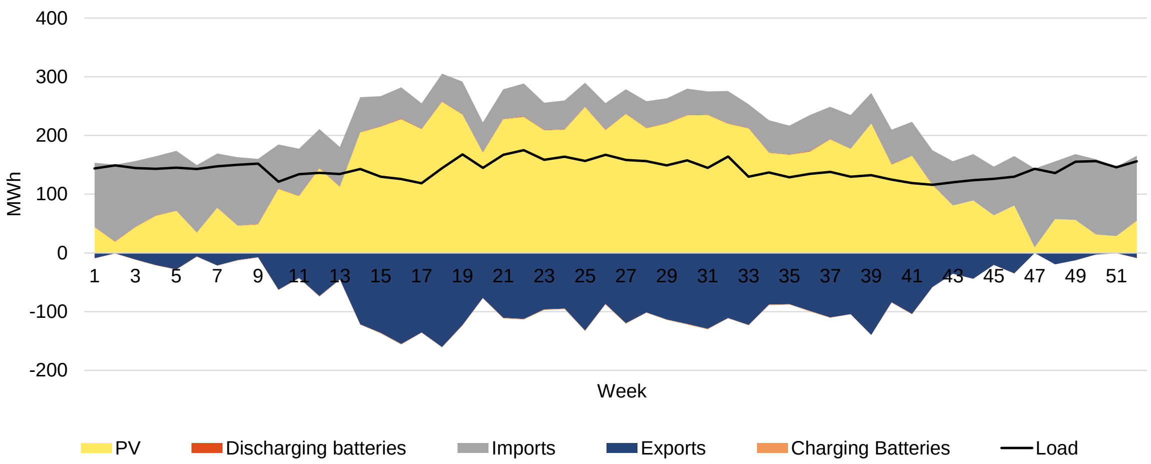

Figure 172: An Annual electric supply according to the Ref-SC in Ollersdorf in 2030

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Figure 173 and Figure 174 illustrate the hourly electricity supply profile for the village of Ollersdorf for the two central weeks of December and first two weeks of July in 2030, respectively. Both figures show how **the surplus of electricity production by PV is exported to the national grid and, in minor portion to charge electric batteries**. The highest export takes place during summertime, as the radiation is higher than in wintertime. In addition, the 5 MW transmission line which connects the village of Ollersdorf to the national grid has enough capacity to avoid curtailments of PV panels.

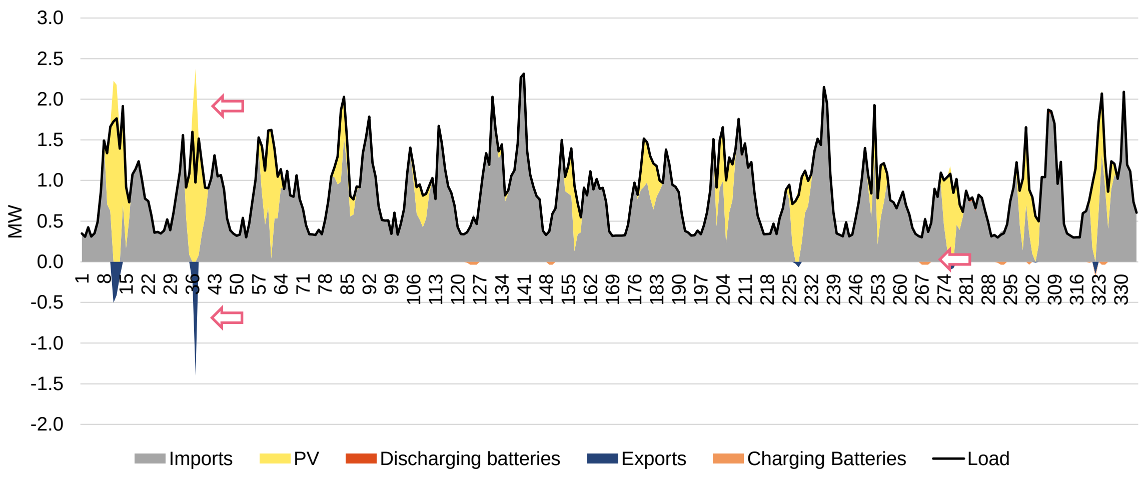

Figure 173: Hourly electricity production in the two central weeks of December according to the Ref-SC in the village of Ollersdorf in 2030

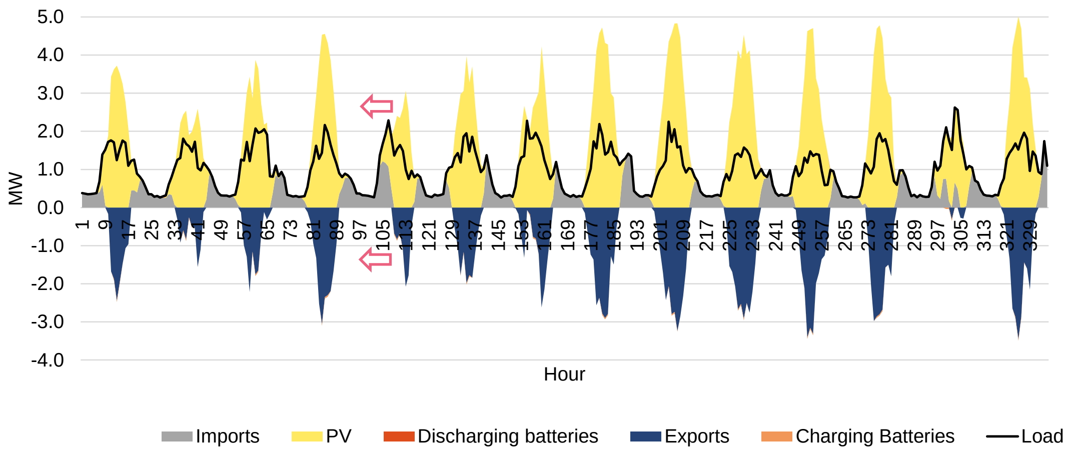

Figure 174: Hourly electricity production in the first two week of July according to the Ref-SC in the village of Ollersdorf in 2030

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HEATING SECTOR

Figure 175 shows the annual heat supply in the Ref-SC per week in 2030 by heat production technologies. In the village of Ollersdorf, **heat is produced and consumed locally, without the possibility of heat trading with an external network outside the community**[9]. The total heat production is estimated as 7,217 MWh (including distribution losses) on an annual basis. **Biomass boilers are the main heat source** with 2,797 MWh followed by natural gas boilers with 2,619 MWh, which represent 38% and 41% of the total heat supply, respectively. Despite HPs (air-source HPs and geothermal HPs) constitute a low electricity demand, they can supply 492 MWh of heat due to the COP of these technologies. Thermal solar panels have a small contribution with 23 MWh, and thermal storage linked to this technology can balance around 5 MWh on an annual basis.

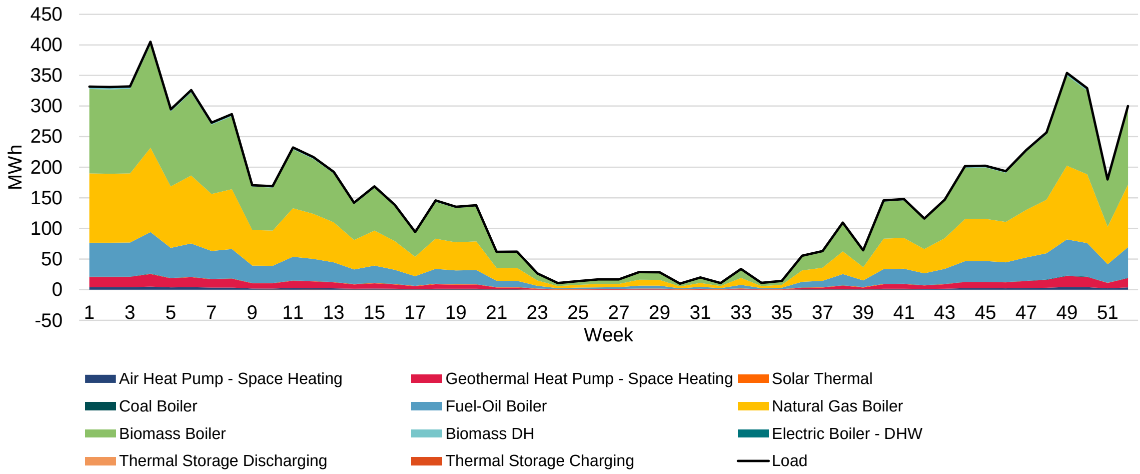

Figure 175: Annual heat production by technology according to the Ref-SC in Ollersdorf in 2030

Figure 176 and Figure 177 illustrate hourly heat production profiles for the two central weeks of December and first two weeks of July in 2030, respectively. Thermal storage is in operation for few hours only during the winter period due to the low solar radiation. During the summer period, heat storage systems are more active to store the surplus heat generated from the solar thermal panels and shift this heat to another period. However, its contribution is very limited during the wintertime, being directly supply the dominated operational model by the boilers and HPs located in the village.

[9] This chart and the following ones are focussed on space heating and DHW, therefore, they do not include the industrial and agriculture sectors.

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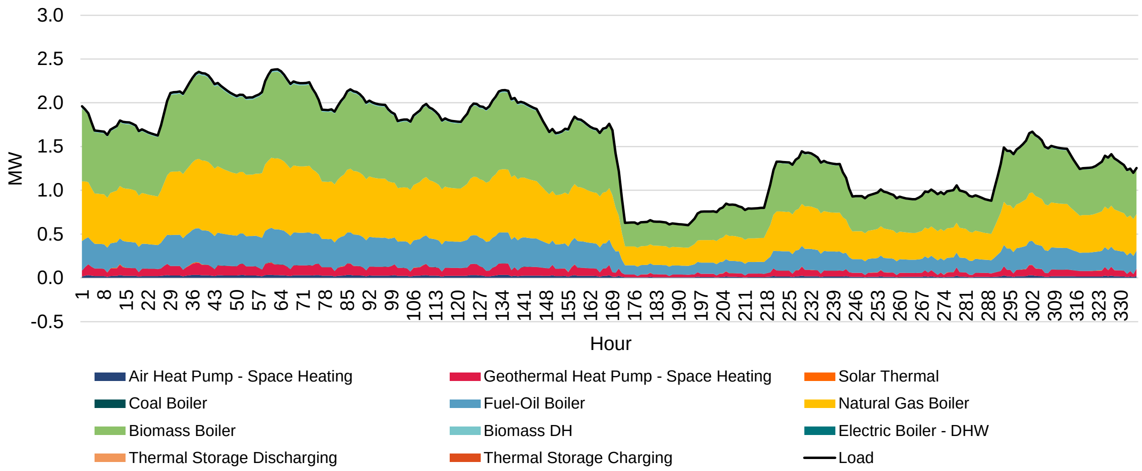

Figure 176: Hourly heat production by technologies in the two central weeks of December according to the Ref-SC in the village of Ollersdorf in 2030

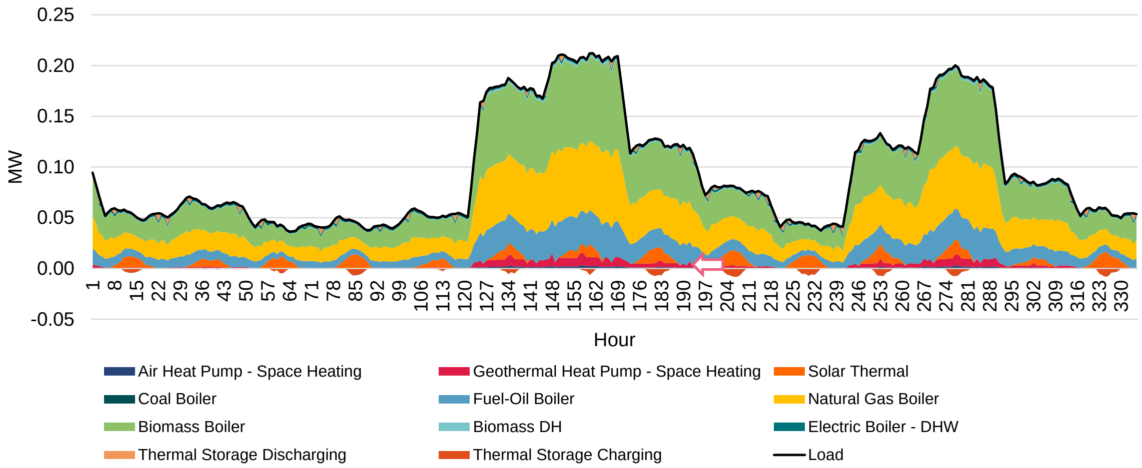

Figure 177: Hourly heat production by technology in the first two weeks of July according to the Ref-SC in the village of Ollersdorf in 2030

CO_2 EMMISSIONS

Figure 178 shows the direct and indirect CO_2 emissions by sector of the Ref-SC in Ollersdorf. The total CO_2 emissions account for 3,028 tons of CO_2, being all of them direct emissions. The electricity energy balance achieved under this scenario does not impact on the reduction of the indirect CO_2 emissions due to the consumption from the national grid, as the Austrian electric system will be carbon neutral (i.e. 0 tons of CO_2 by MWh) in 2030 according to the Austrian NECP (European Commission, 2022). Under this scenario, there is a reduction of 19% in the overall CO_2 emissions compared to the base year due to the increase of local renewable production, the use of HPs and the carbon neutrality of the grid. The transport sector is the main emitting sector with 1,553 tons of CO_2 of overall direct CO_2 emissions; 51% of the total. The residential sector has the highest direct CO_2 emissions reduction, accounting for 765 tons of CO_2; 9% less compared to the base year.

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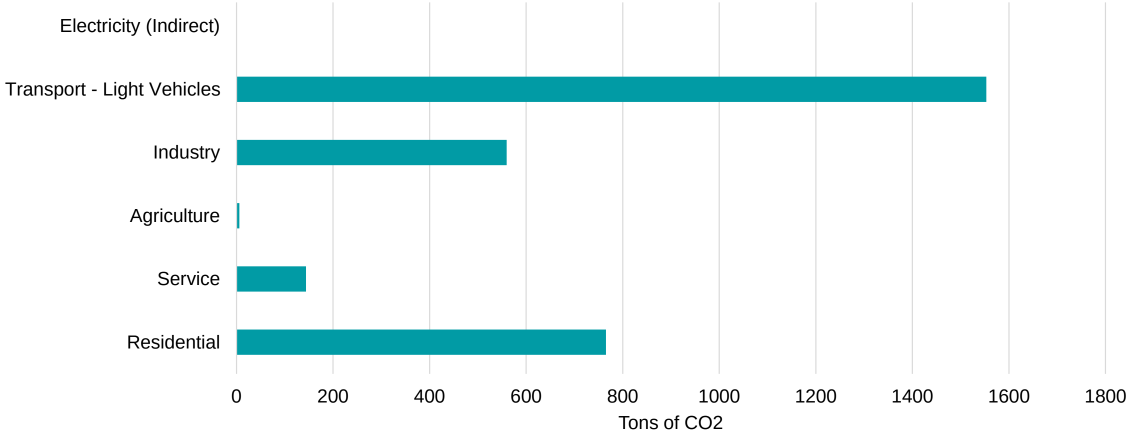

Figure 178: CO_2 emissions by sector of Ref-SC scenario in the village of Ollersdorf

6.5.2. BK-SC

This scenario explores **how flexible measures and local resources can support mitigating blackout events and reducing the dependence on the national grid**. To assess how the system performs within this event, **a blackout is forced** in the transmission line of the village of Ollersdorf **during the most critical time**.

The residual load is used as indicator to identify the most critical time when the village is more dependent on the transmission line connected to the village, and is defined as the load at each time minus the local electricity production from vRES, such as PV panels and wind production. Figure 179 shows the residual load for Ollersdorf. The positive values are the hours when the load is higher than the electricity production from PV and wind, implying a high dependence on the transmission line and where other flexibility measures such as electric batteries can be more active to prevent the blackout. Negative values represent the PV surplus, meaning that local electricity production from PV exceeds the load. **The highest positive value of the residual load is 2.59 MW and takes place during the 14th of December** (hour number 8373 of the year). At this moment, **a blackout is forced in the model avoiding electricity exports and imports** in Ollersdorf.

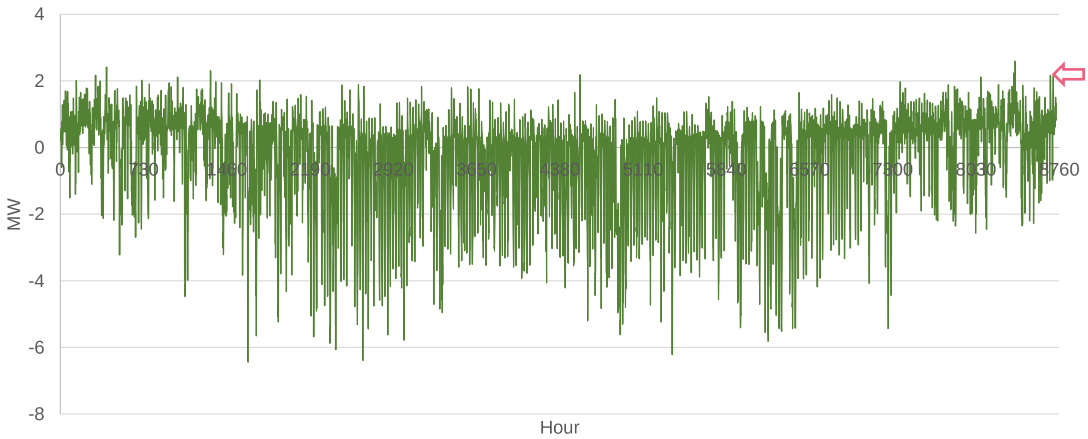

Figure 179: Residual load for the village of Ollersdorf

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Figure 180 shows the overall local installed heat and electricity production capacities and the electricity transmission line capacity for the BK-SC. In this scenario, PV capacity experiences a high increase like in the Ref-SC, with an installed capacity of 7.1 MWp, and **wind production appears as part of the local electricity production mix**, with an installed capacity of 3.2 MW. This increase in the electric production capacity is consequence of the rise of the electricity demand in this scenario while keeping electric energy balance in the village. The BK-SC is linked to DMD-ELC demand scenario that considers the complete replacement of fossil fuel boilers in the residential and service sector by HPs as well as a full electrification of light vehicles. Electric batteries capacity grows up to 8.2 MWh to be able to cover the electricity demand during the blackout events.

In the heating sector, there is a reduction of the installed heating capacity compared to the Ref-SC because the higher efficiency of HPs with respect to conventional fossil fuel-based boilers. **Air-source HPs for space heating are the main technology** with 1.4 MW followed by biomass boilers with an installed heat capacity of 1.2 MW. Solar thermal panels and thermal storage play a minor role in the heating sector as in the Ref-SC.

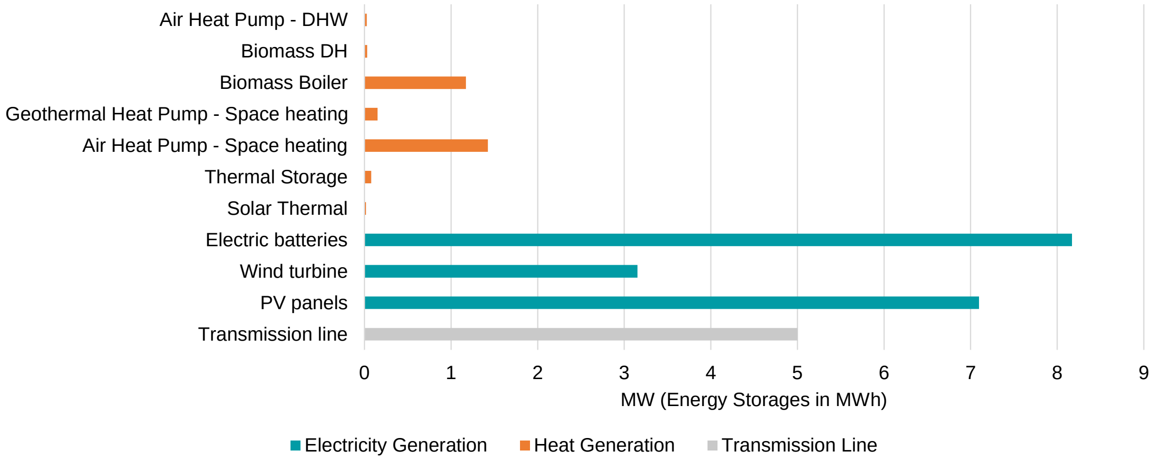

Figure 180: Local installed heat and electricity production capacities by technology and electricity transmission line capacity according to the BK-SC in the village of Ollersdorf in 2030

ELECTRIC SECTOR

Figure 181 shows the annual electricity demand in the BK-SC as well as the impact of DSM per week in 2030. The total electricity demand is estimated as 11,166 MWh (including of electricity distribution losses) on annual basis; 50% higher compared to the Ref-SC. **Electric appliances are the main electricity consumers** with 7,260 MWh followed by EVs with 2,695 MWh, representing 65% and 24% of share of the total electricity demand, respectively. Electricity consumption of the HPs (air and geothermal HPs) is 1,150 MW and can represent up to 24% in winter period as in the last week of January. **DSM has a higher role compared to the Ref-SC**, being able to shift around 65 MWh of the space heating demand since the highest air-source HPs of this technology generates a higher potential for this flexibility measure.

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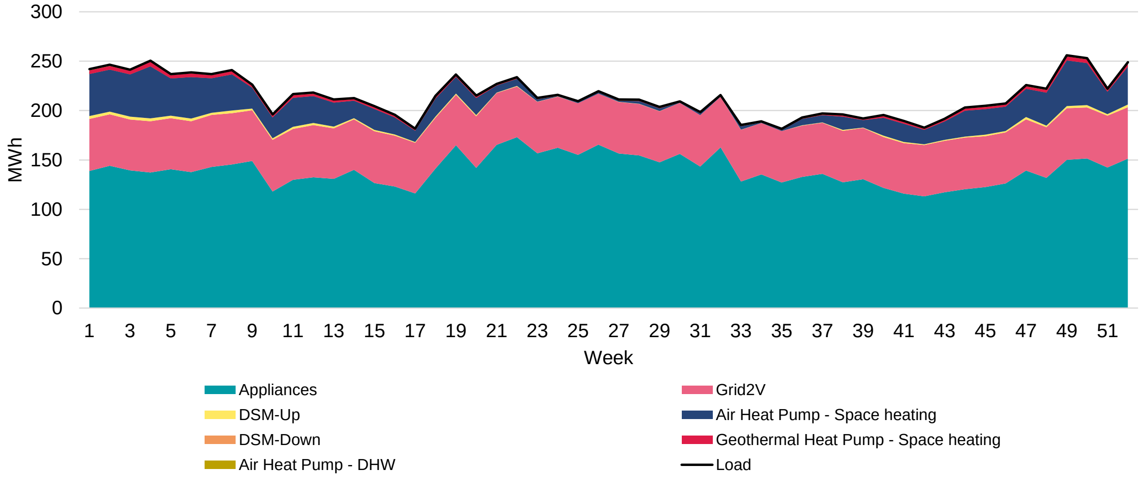

Figure 181: Annual electric demand by technology according to the BK-SC in Ollersdorf in 2030

Figure 182 and Figure 183 illustrate hourly electricity demand profiles for the two central weeks of December and first two weeks of July in 2030, respectively. **DSM has a low impact on the modification of the overall electricity demand profile** as the electricity consumption by HPs is relatively low compared to the electricity consumption of appliances. However, **charging of EVs produces a saw-tooth consumption profile due to the high number of EVs connected to the grid and to the use of smart-charging** in which the batteries are charged in the moment of the day with the lowest electricity price. The load peaks caused by the EVs can be up to 94% of the overall electricity demand in some hours, and in average 44% of the hourly load when the EVs are charging.

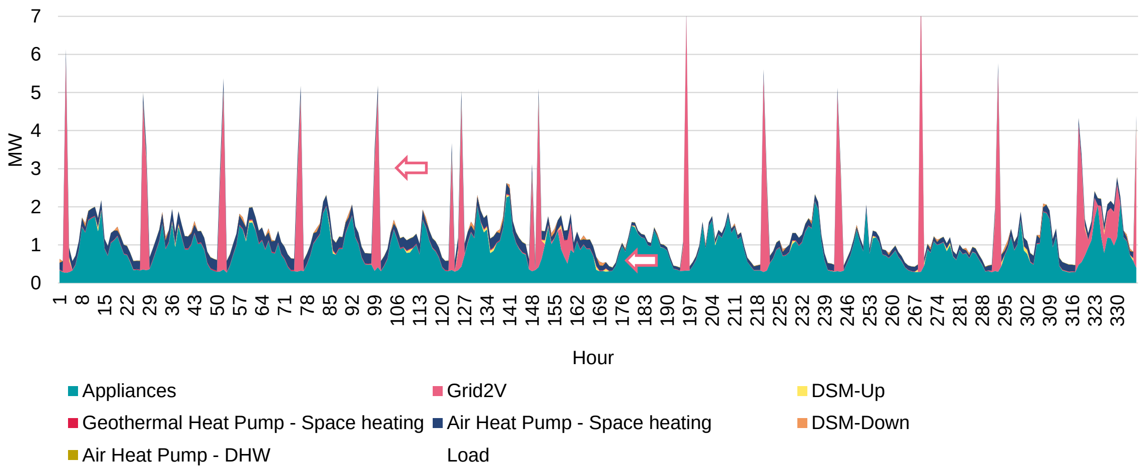

Figure 182: Hourly electricity demand in the two central weeks of December according to the BK-SC in the village of Ollersdorf in 2030

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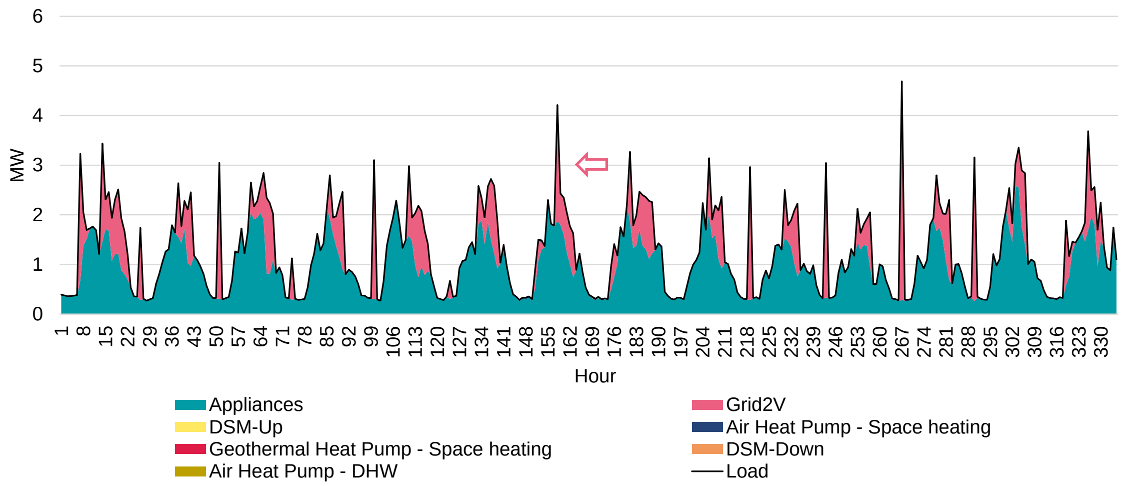

Figure 183: Hourly electricity demand in the first two weeks of July for the BK-SC in Ollersdorf in 2030

Figure 184 shows the annual electricity supply per week in the BK-SC from local resources, imports and exports, as well as the charging and discharging of batteries to balance the electricity system in 2030. Positive values represent electricity supply of different options to meet the electricity demand, whereas the negative values correspond to the electricity that is either stored in batteries or exported. The annual locally-generated electricity in the village of Ollersdorf is 11,645 MWh (including transmission losses). PV generates 7,431 MWh and the remaining part is produced by wind. The high capacity of electric battery allows to balance 2,161 MWh during the year, i.e. 19% of the electric demand. Electricity import are 6,211 MWh, the same as the electricity export and 65% more compared to the Ref-SC. The dependence of the electric imports is higher in wintertime and can cover up 90% of the load as in the second week of January. However, **the transmission line capacity of 5 MW is not big enough to absorb all the electricity production surplus resulting in curtailment of PV and wind** in certain moments. This lack of capacity in the transmission line avoids additional electricity exports from the local production to national grid of around 2,231 MWh.

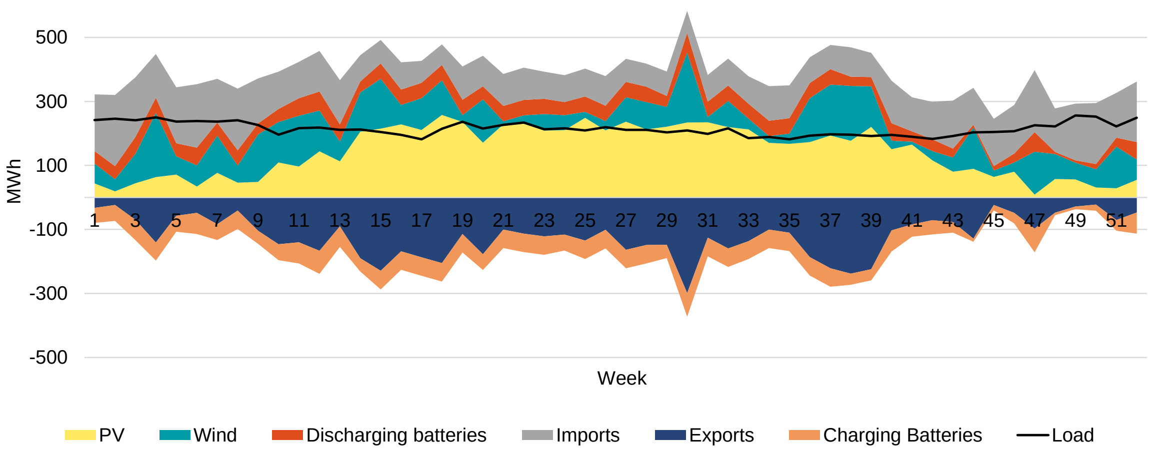

Figure 184: Annual electric supply according to the BK-SC in the village of Ollersdorf in 2030

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Figure 185 and Figure 186 illustrate the hourly electricity supply profile for the village of Ollersdorf for the two central weeks of December and first two weeks of July in 2030, respectively. Figure 185 shows that the simulated blackout takes place on the 14th of December (hour 141 in the figure) showing that **there is enough electric storage capacity to cover the most critical blackout period**. Both figures show how the generated electricity surplus from PV and wind can be stored in batteries and can be used later or exported to the national grid, which would increase the revenue for the community. Furthermore, **the batteries are charged also by imported electricity during the times when electricity prices are low**, increasing the trading with the national grid. Moreover, price-based operation (controlled charging) of batteries leads to electricity being traded effectively with the national grid.

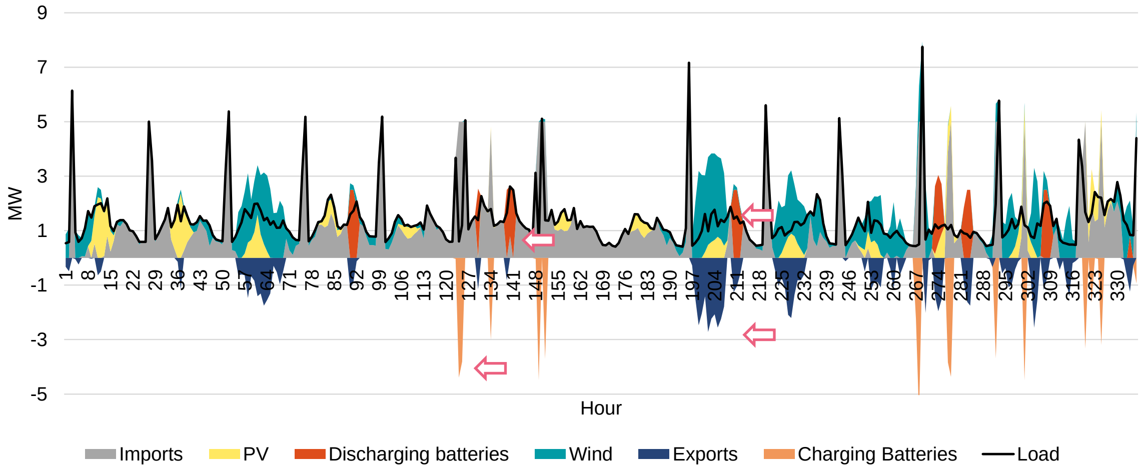

Figure 185: Hourly electricity production in the two centre weeks of December according to the BK-SC in the village of Ollersdorf in 2030

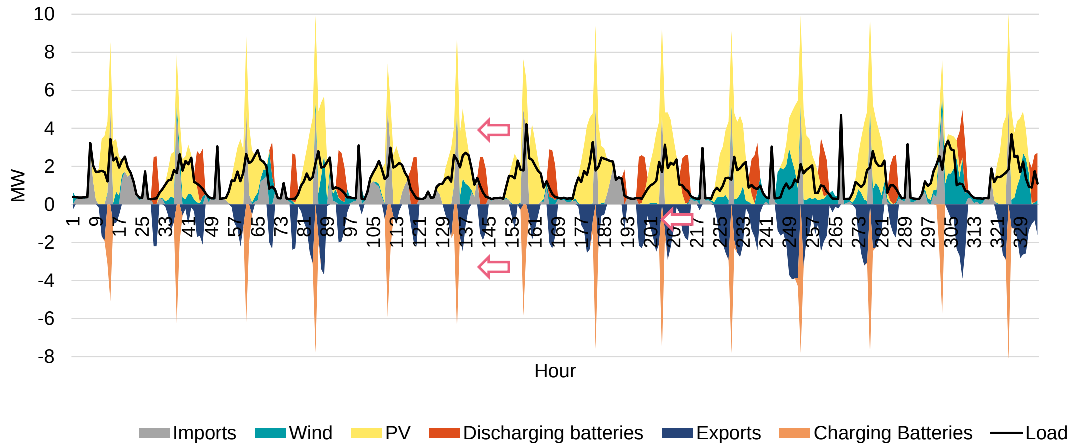

Figure 186: Hourly electricity production in the first two weeks of July according to the BK-SC in the village of Ollersdorf in 2030

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HEATING SECTOR

Figure 187 shows the annual heat supply in the BK-SC per week in 2030 by heat production technologies. In the village of Ollersdorf, as for the Ref-SC, heat is produced and consumed locally, without the possibility of heat trading with an external network outside the community. The total heat production is estimated as 7,043 MWh (including distribution losses) on an annual basis. **Air-source HPs for space heating are the main heat source** with 3,750 MWh followed by biomass boilers with 2,797 MWh, which represent 53% and 40% of the total heat supply, respectively. Thermal solar panels have a small contribution with 23 MWh as in the Ref-SC; however, thermal storage can balance a higher amount of heat reaching 12 MWh on an annual basis.

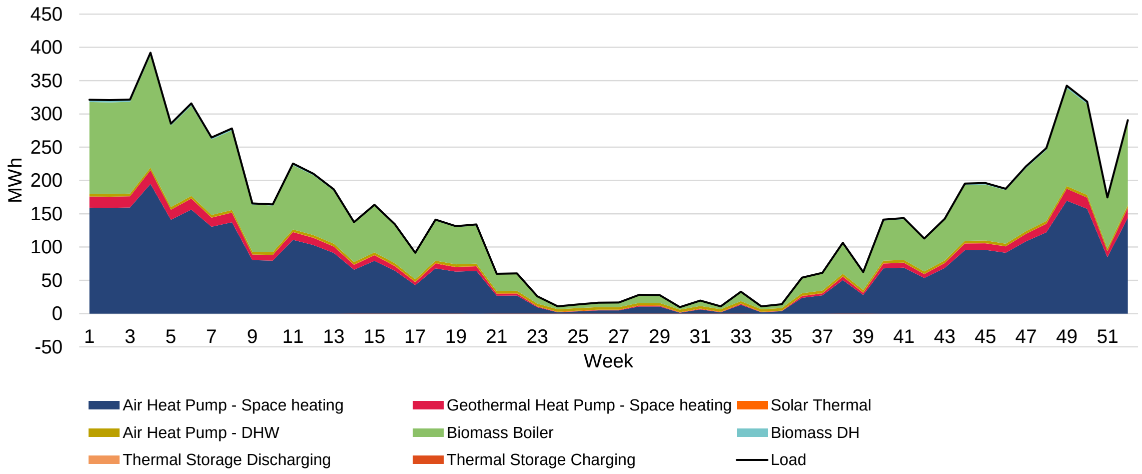

Figure 187: Annual heat production by technology for the BK-SC in Ollersdorf in 2030

Figure 188 and Figure 189 illustrate hourly heat production profiles for the two central weeks of December and first two weeks of July in 2030. **The heat production profile is characterized by a sequence of peaks and valleys due to a high proportion of HPs contributing to cover the space heating heat demand and the DSM system** connected to these technologies. DSM has a high impact on the overall heat demand profile because the COP of the HPs in the heat profile multiplies the impact of the variations of the DSM in the electricity profile. Thermal storage is in operation only for few hours during the winter period due the low solar radiation, being more active during the summertime due to heat surplus generated from the solar thermal panels. Moreover, during the summer period thermal storage systems are also charged with the heat generated from the air-source HPs when the electricity prices are lower, and discharged when electricity prices are higher.

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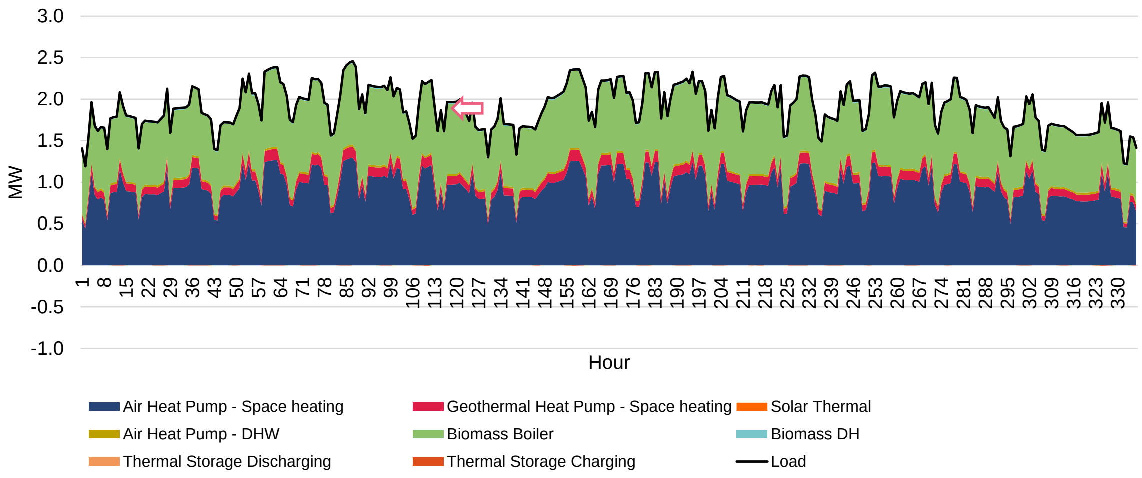

Figure 188: Hourly heat production in the two central weeks of December according to the BK-SC in the village of Ollersdorf in 2030

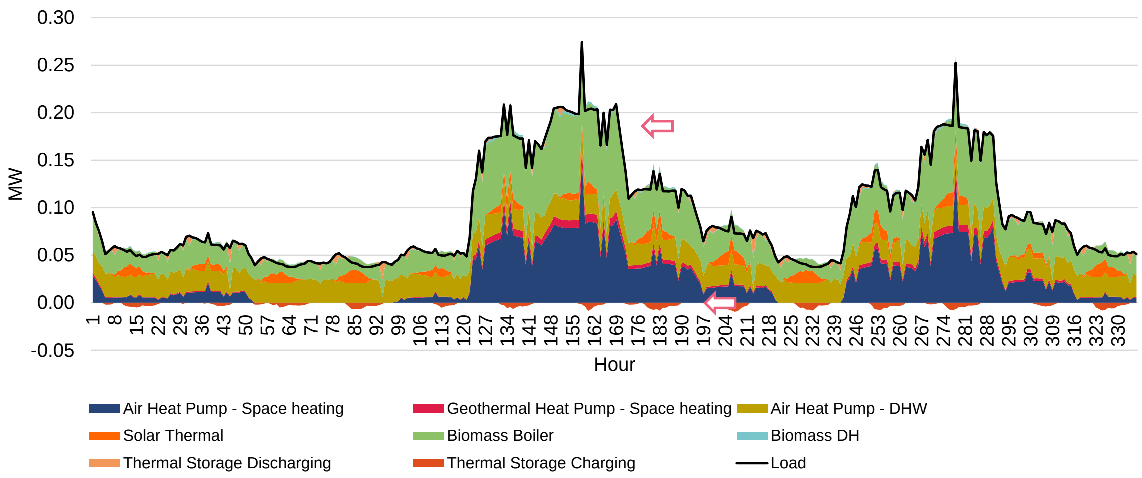

Figure 189: Hourly heat production in the first two weeks of July according to the BK-SC in the village of Ollersdorf in 2030

CO_2 EMMISSIONS

In the BK-SC scenario the full decarbonization of the village of Ollersdorf is achieved. This is due to the replacement of all fossil fuel boilers by HPs in the residential and service sectors and in the agriculture and industrial sectors by biomass boilers, together with the full penetration of the EVs. The electricity energy balance achieved by Ollersdorf under this scenario does not have an impact on the reduction of the indirect CO_2 emissions due to the electricity consumption from the national grid, as the Austrian electric system will be carbon neutral (0 tons of CO_2 by MWh) in 2030 according to the Austrian NECP (European Commission, 2022).

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6.5.3. H2T-SC

Figure 190 shows the overall local installed heat and electricity production capacities and the electricity transmission line capacity for the H2T-SC. **This scenario performs in a similar way as the BK-SC because the hydrogen production to refuel H_2-Buses is minor compared to overall energy needs.** In this context, PV and wind capacity, like in the BK-SC, accounts for 7.1 MWp and 3.2 MW, respectively. Electric batteries capacity, to cover the electricity demand during the blackout events, grows up to 8.3 MWh, representing a slight increase with respect to the BK-SC. To generate the 28 MWh of hydrogen to refuel the H_2-Buses, it is necessary to install a small hydrogen system with an electrolyser of 8.3 kW capacity linked to a hydrogen storage with a capacity of 112 kWh.

In the heating sector, like in the BK-SC, **air-source HPs for space heating are the main technology** with 1.4 MW followed by biomass boilers with an installed heat capacity of 1.2 MW. Solar thermal panels and thermal storage play a minor role in the heating sector as in the Ref-SC.

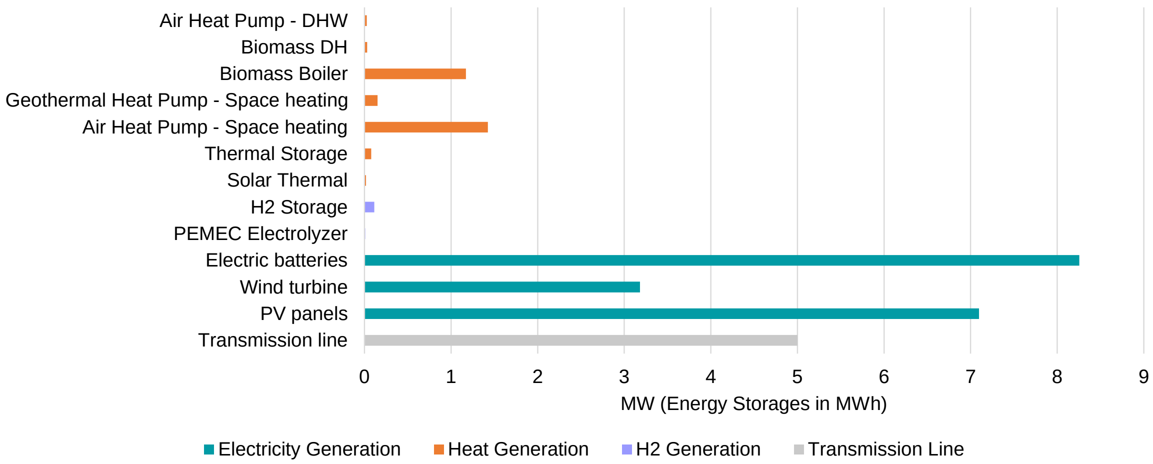

Figure 190: Installed local heat and electricity production capacities by technology and electricity transmission line capacity according to the H2T-SC in the village of Ollersdorf in 2030

ELECTRIC SECTOR

Figure 191 shows the annual electricity demand in the H2T-SC as well as the impact of DSM per week in 2030. The total electricity demand is estimated at 11,204 MWh (including distribution losses) on an annual basis. As for the BK-SC, **electric appliances are the main electricity consumers** with 7,260 MWh followed by EVs 2,695 MWh, with 65% and 24% shares of the total electricity demand, respectively. The electricity consumption of HPs (air and geothermal HPs) is 1,150 MW, with DSM being able to shift around 65 MWh of the electricity consumption from these technologies. Finally, the electricity consumption of the electrolyser to generate the hydrogen for the H_2-Buses is 38 MWh.

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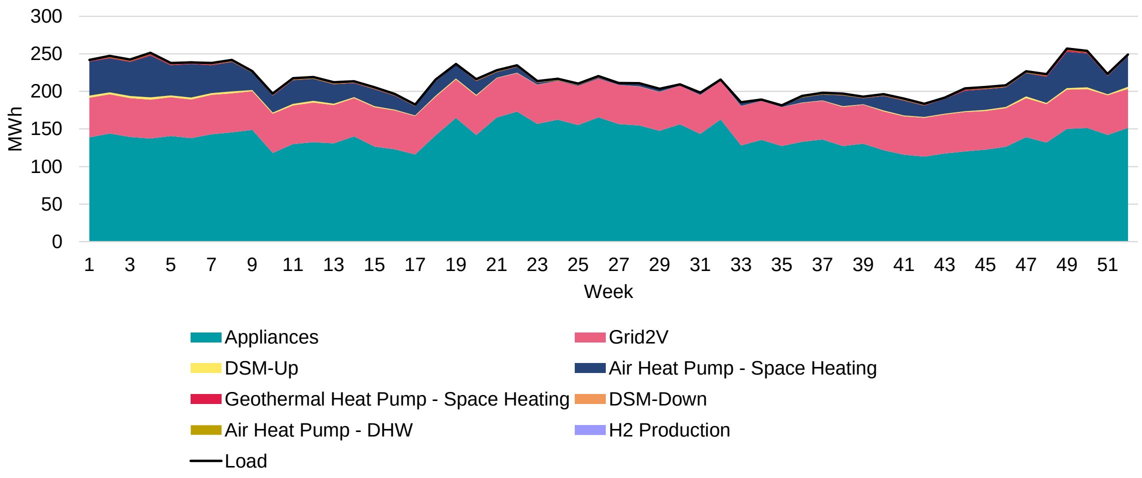

Figure 191: Annual electricity demand by technology according to the H2T-SC in Ollersdorf in 2030

Figure 192 and Figure 193 illustrate hourly electricity demand profiles for the two central weeks of December and first two weeks of July in 2030, respectively. Like in the BK-SC, **DSM has a low impact on the modification of the overall electricity demand profile** as the electricity consumption by the HPs is relatively low compared to the electricity consumption of appliances. However, charging of EVs produces a saw-tooth consumption profile due to the high number of EVs connected to the grid and to the use of smart-charging in which the batteries are charged in the moment of the day with the lowest electricity price. **The impact of the electrolyser on the electricity profile is minor**, repressing less than 1% of the overall electricity demand in the hours when it is switched on.

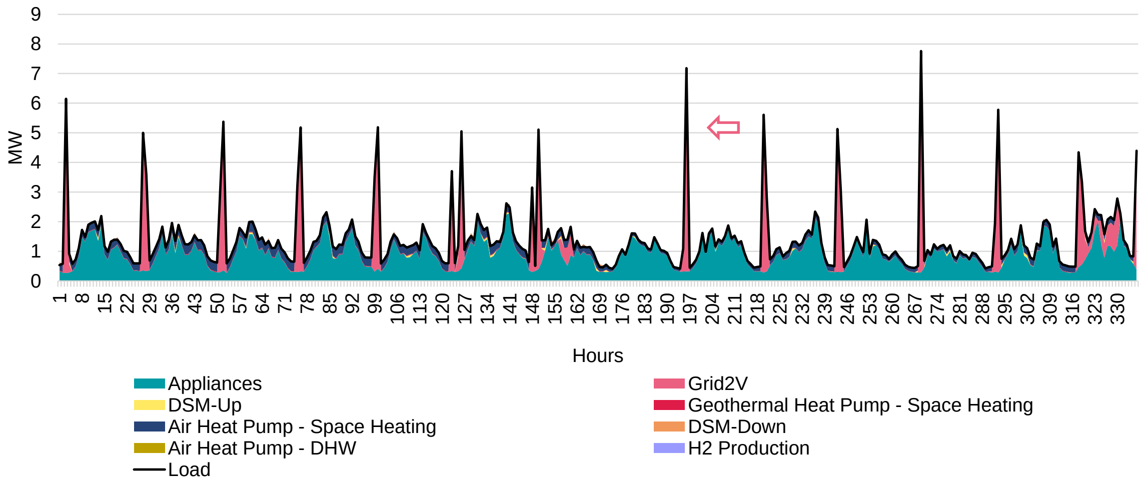

Figure 192: Hourly electricity demand in the two central weeks of December according to the H2T-SC in the village of Ollersdorf in 2030

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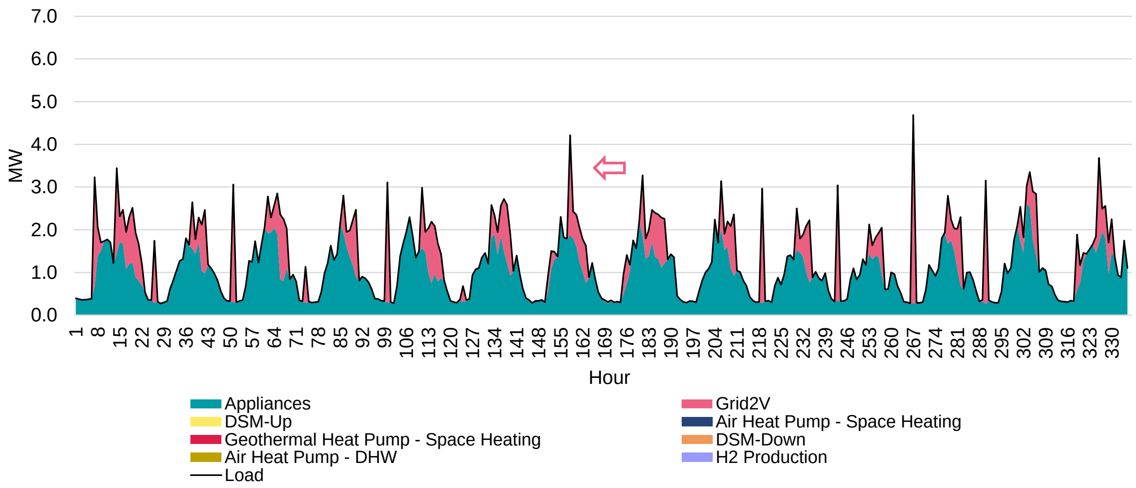

Figure 193: Hourly electricity demand in the first two weeks of July for the H2T-SC in Ollersdorf in 2030

Figure 194 shows the annual electricity supply per week in the H2T-SC from local resources, imports and exports as well as the charging and discharging of batteries to balance the electricity system in 2030. Positive values represent the electricity supply of different options to meet the electricity demand, whereas the negative values consist of the electricity that is either stored in batteries or exported. The annual locally-generated electricity in the village of Ollersdorf is 11,682 MWh (including transmission losses), slightly more compared to the BK-SC. PV generates 7,431 MWh and the remaining part is produced by wind. The high capacity of electric battery allows to balance 2,161 MWh during the year, around 19% of the electric demand. Electricity imports are 6,222 MWh, the same as the electricity export. However, **the transmission line** capacity of 5 MW **is not big enough to absorb all the electricity production surplus, resulting in curtailments** of PV and wind electricity in certain moments. This lack of capacity in the transmission line avoids additional electricity exports from the local production to national grid of around 2,229 MWh.

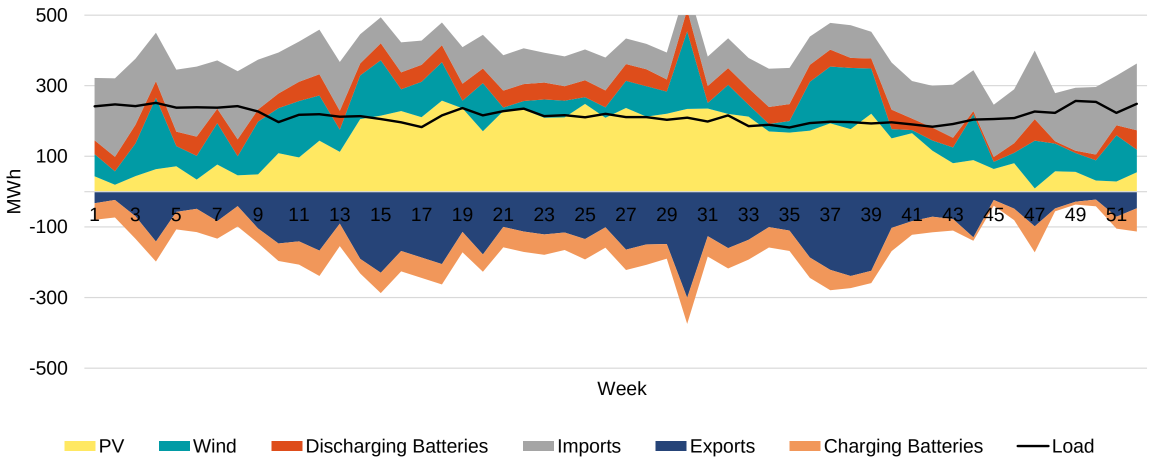

Figure 194: An Annual electric supply according to the H2T-SC in Ollersdorf in 2030

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Figure 195 and Figure 196 illustrate the hourly electricity supply profile for the village of Ollersdorf for the two central weeks of December and first two weeks of July respectively in 2030, respectively. Figure 195 shows that the simulated blackout takes place on the14th of December (hours 141, same as for the BK-SC) showing that there is enough electric storage capacity to cover the most critical blackout period like in H2T-SC. **During the blackout the electrolyser reacts stopping the hydrogen production**. Both figures show how the generated electricity surplus from PV and wind can be stored in the electric batteries, as well as electricity imports when electricity prices are low to be used later or exported. This increases the trading with the national grid and the revenue for the energy community.

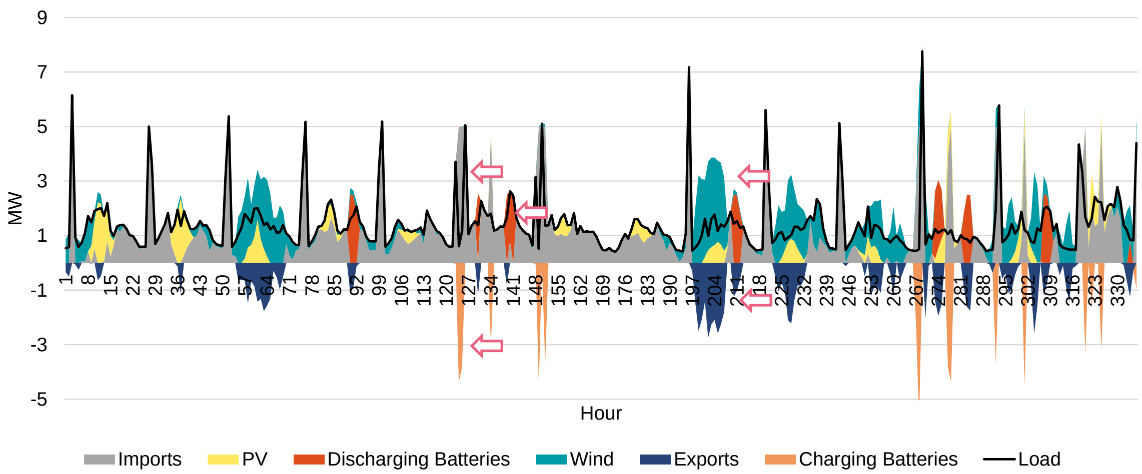

Figure 195: Hourly electricity production in the two central weeks of December according to the H2T-SC in the village of Ollersdorf in 2030

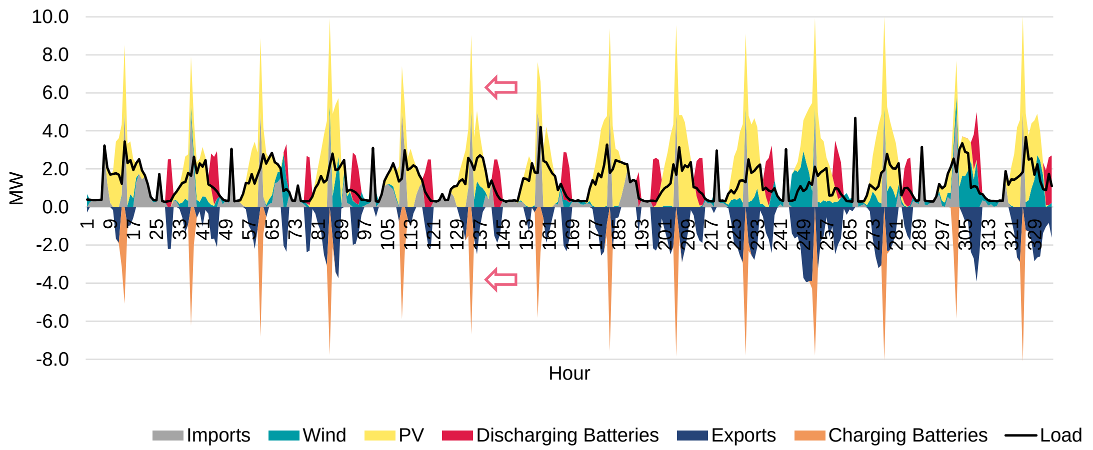

Figure 196: Hourly electricity production in the first two week of July according to the H2T-SC in the village of Ollersdorf in 2030

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HEATING SECTOR

Figure 197 shows the annual heat supply in the H2T-SC per week in 2030 by heat production technologies. As for the two other scenarios, in the village of Ollersdorf heat is produced and consumed locally, without the possibility of heat trading with an external network outside the community. This sector performs like in the BK-SC; the total heat production is estimated as 7,043 MWh (including distribution losses) on an annual basis. **Air-source HPs for space heating are the main heat source** with 3,750 MWh followed by biomass boilers with 2,797 MWh, which represent 53% and 40% of the total heat supply, respectively. Thermal solar panels have a small contribution with 23 MWh. However, thermal storage systems can balance a higher among of heat reaching 12 MWh on an annual basis.

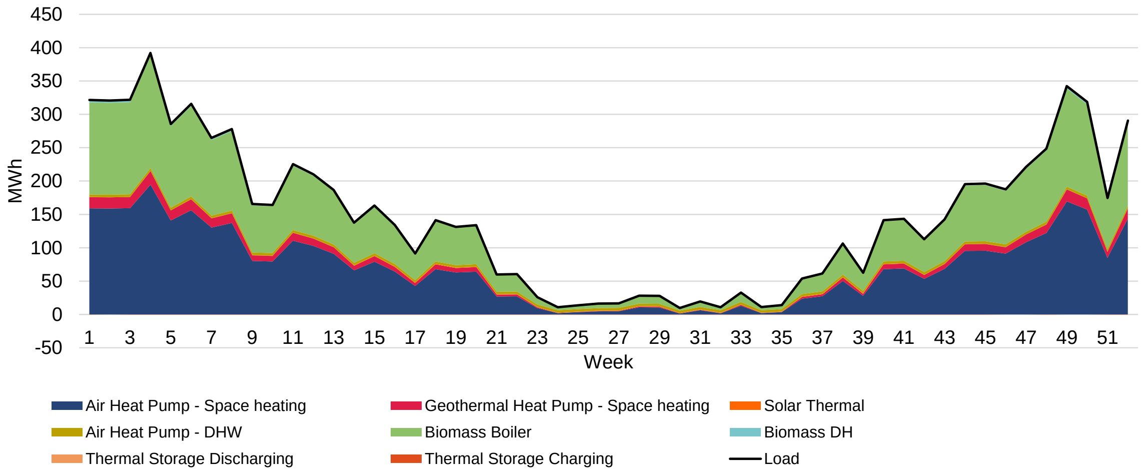

Figure 197: Annual heat production by technology according to the H2T-SC in the village of Ollersdorf in 2030

Figure 198and Figure 199 illustrate hourly heat production profiles for the two central weeks of December and first two weeks of July in 2030. As for the BK-SC, the heat production profile is characterized by a sequence of peaks and valleys. This is because of a high proportion of HPs contributing to cover the space heating heat demand and the DSM system connected to these technologies. **DSM has a high impact on the overall heat demand profile** because the COP of the HPs multiplies in the heat profile the impact of the variations of the DSM in the electricity profile. Thermal storage is in operation for few hours only during the winter period due the low solar radiation, being more active during the summertime due to the surplus heat generated from the solar thermal panels. Furthermore, during the summer period thermal storage systems are also charged with the heat generated from the air-source HPs, when the electricity prices are lower, and discharged when electricity prices are higher.

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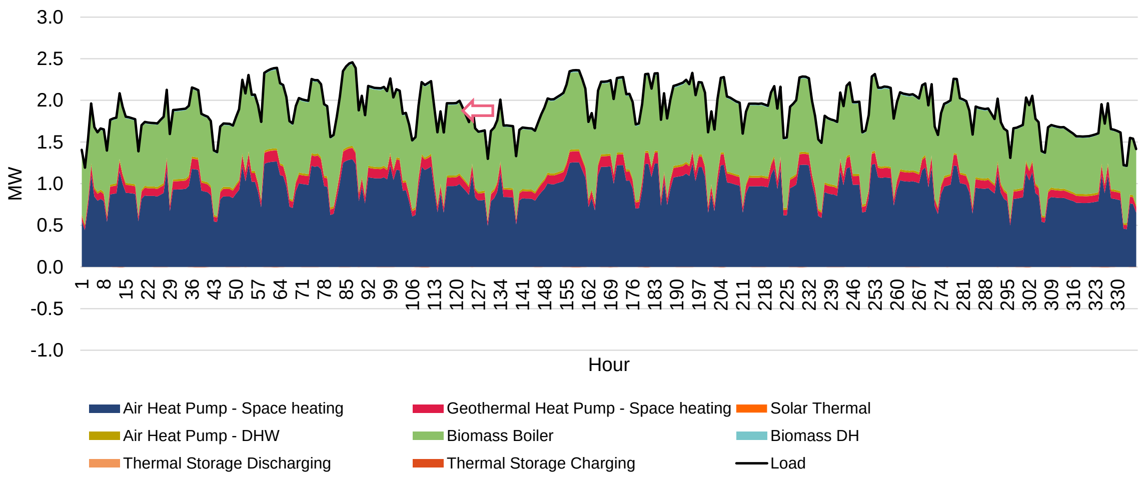

Figure 198: Hourly heat production by technologies in the two central weeks of December according to the H2T-SC in the village of Ollersdorf in 2030

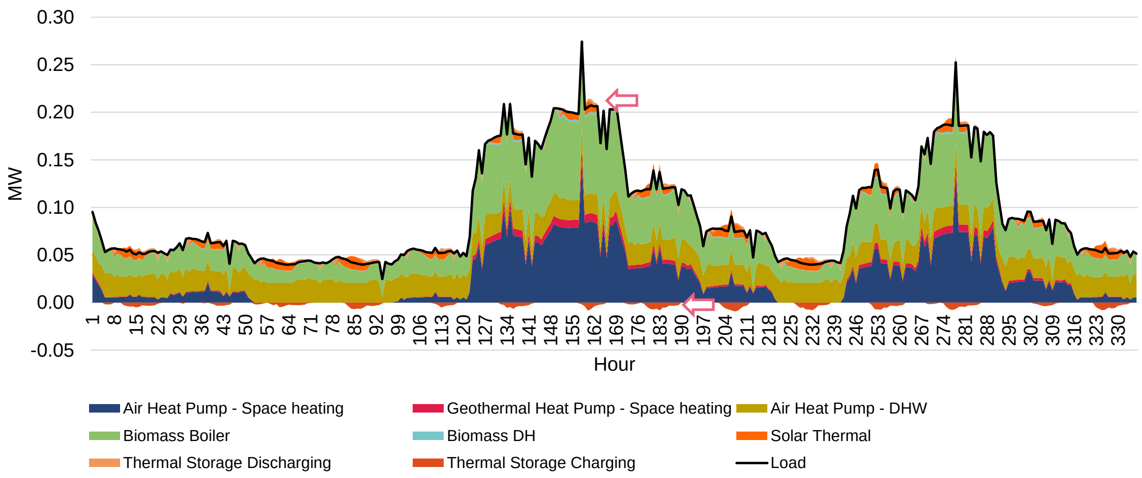

Figure 199: Hourly heat production by technology in the first two weeks according to July of the H2T-SC in the village of Ollersdorf in 2030

HYDROGEN SECTOR

In the H2T-SC, a yearly energy consumption of 28 MWh of hydrogen must be generated by an electrolyser located in Ollersdorf. Hydrogen flows between the electrolyser, the hydrogen storage, and the hydrogen load (H_2-Buses) as exemplified by Figure 200. This figure illustrates the hourly hydrogen production and consumption profiles for the two central weeks of December 2030 as a sample of how the hydrogen system performs during a school week. **The electrolyser located in the village works with a constant load along during the school days charging continuously the hydrogen storage**. When H_2-Buses arrive to the parking, they are refuelled by discharging the hydrogen storage in combination of additional hydrogen generated by the electrolyser. During the weekends, when the H_2-Buses are not needed, the hydrogen storage is charged by the electrolyser when the electricity prices are low.

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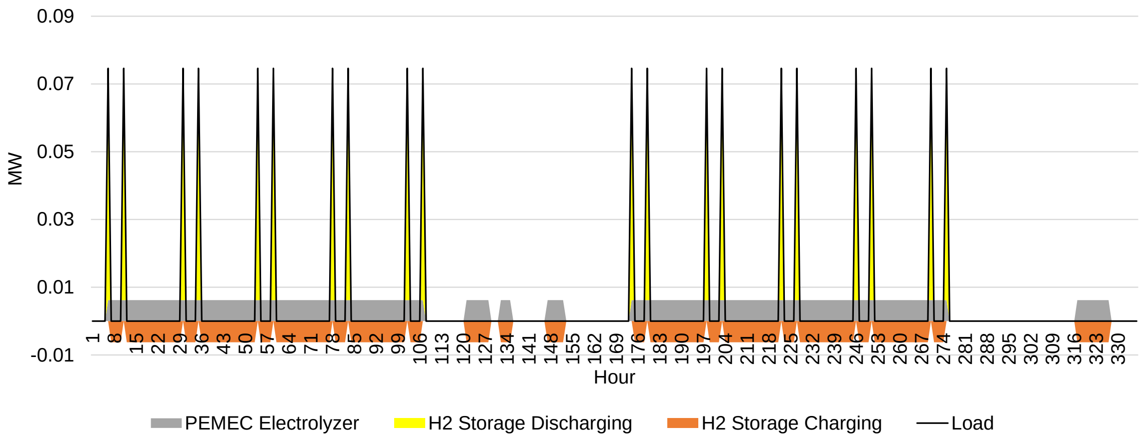

Figure 200: Hourly hydrogen production and refuelling of the H_2-Buses in the two central weeks of December according to the H2T-SC for the village of Ollersdorf in 2030

CO_2 EMMISSIONS

In the same way as for the BK-SC scenario, in the H2T scenario the full decarbonization of Ollersdorf is achieved. This is due to the replacement of all fossil fuel boilers in the residential and service sector by HPs and in the agriculture and industrial sectors by biomass boilers, together with the full penetration of the EVs. The electricity energy balance achieved by the village of Ollersdorf under this scenario does not have an impact on the reduction of the indirect CO_2 emissions due to the electricity consumption from the national grid, as the Austrian electric system will be carbon neutral (0 tons of CO_2 by MWh) in 2030 according with the Austrian NECP (European Commission, 2022).

6.6. Comparison of Scenarios

6.6.1. Electric sector

Figure 201 shows the comparison of the capacity of the local electric production sources and the transmission line of the scenarios and the base year in the village of Ollersdorf. For all the assessed scenarios, PV capacity has a high increase compared to base year with an installed capacity of 7.1 MWp. In the BK-SC and the H2T-SC scenario, there is an additional need of 3.2 MW of wind capacity to cover the high increase of the electricity demand. In the Ref-SC scenario, the capacity of electric batteries is relatively low because the transmission line capacity of 5 MW is high enough to allow a proper electricity exchange between the national grid and the village. However, for the BK-SC scenario and the H2T-SC scenario the capacity of electric batteries grows up to around to 8.2 MWh to be able to cover the electricity demand during the black-out events.

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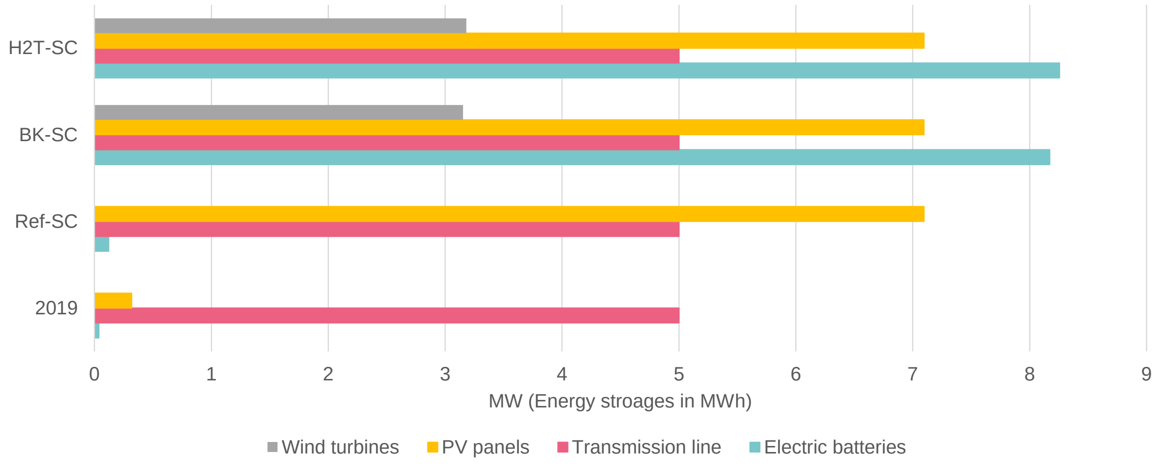

Figure 201: Comparison of the electric capacity of the local electric production sources and the transmission line of the scenarios and base year in the village of Ollersdorf

Figure 202 shows the comparison of the electricity demand, production, imports and exports of the scenarios and the base year in Ollersdorf. For all the assessed scenarios, there is an increase of the electricity production compared to the base year due to the higher penetration of local PV and wind to achieve the electricity balance in the village. In the Ref-SC scenario, the electricity demand is estimated at 7,424 MWh and the local PV production grows up to 7,431 MWh, twenty-two times more compared to 2019. The BK-SC and the H2T-SC scenarios perform in a similar way in terms of electricity demand, local production, imports, and exports. There is high increase in the demand because of the full replacement of the fossil fuel boilers by HPs and the ICE light vehicles by EVs. The electricity demand in the BK-SC scenario is estimated at 11,166 MWh, and at 11,204 MWh in the H2T-SC scenario. The electricity demand for the H2T-SC scenario is slightly higher due to use of the electrolyser to cover the fuel needs in the school buses. In terms of electricity production, for both scenarios PV production is the same as in the Ref-SC scenario, and wind electricity production is around 4,213 MWh for the BK-SC scenario and 4,251 MWh for the H2T-SC scenario.

Figure 202: Comparison of the electricity demand, production, import and export of the scenarios and base year in the village of Ollersdorf

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6.6.2. Heating sector

Figure 203 shows the comparison of the heating capacity by technology of the scenarios and the base year in Ollersdorf. In the Ref-SC scenario, there are not relevant changes compared to the base year. The biomass boiler is the main heating technology with 1.2 MW followed by fossil fuel boilers. There is a growth in the installed capacity HPs reaching 189 MW, 33% more compared to the base year. The BK-SC and the H2T-SC scenarios perform equally. Tn this sense, air-source HP for space heating is the main technology with 1.4 MW due to the full replacement of the fossil fuel boilers, followed by biomass boilers with an installed heat capacity of 1.2 MW. Solar thermal panels and thermal storage play a minor role in the heating sector, as in the Ref-SC scenario.

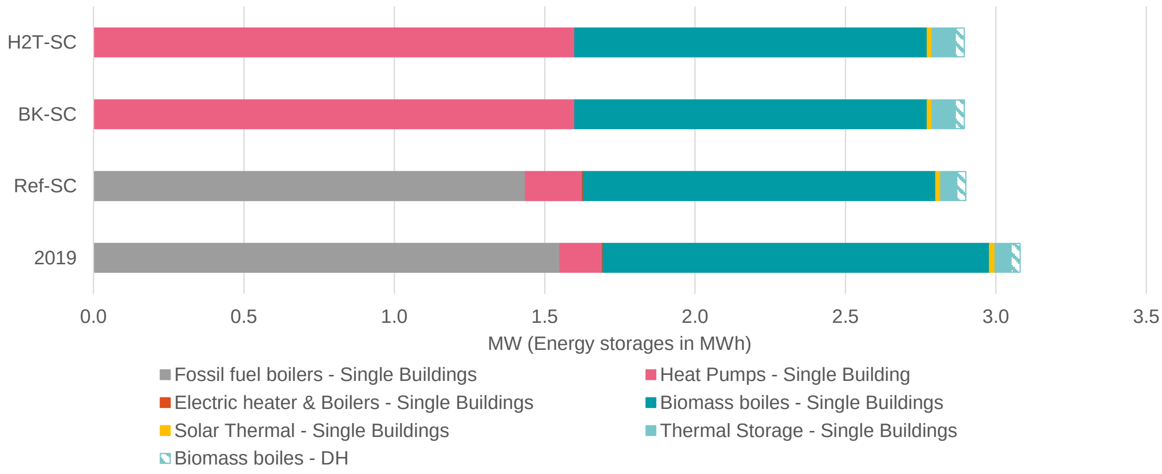

Figure 203: Comparison of the heating capacity by technology of the scenarios and base year in the village of Ollersdorf

Figure 204 shows the comparison of the heat production by technology of the scenarios and the base year in the village of Ollersdorf. For all the assessed scenario there is an overall decrease of around 6% in average of the heat demand due to the improvement of the insulation of the buildings. In parallel, the heat generated from fossil fuels is declined, being the BK-SC and the H2T-SC scenario when they are fully phased-out. The total heat production in the Ref-SC scenario is estimated at 7,217 MWh, with fossil fuel boilers covering 3,804 MWh of the heating needs. Heating renewable technologies are dominated by biomass boilers with a heat production of 2,797 MWh. For the BK-SC and the H2T-SC scenarios, total heat production is estimated at 7,043 MWh. The full replacement of fossil fuel boilers makes HPs become the main heat source with 4,143 MWh of heat, followed by biomass boilers with 2,797 MWh. Thermal solar panels have a small contribution with 23 MWh, as in the Ref-SC scenario.

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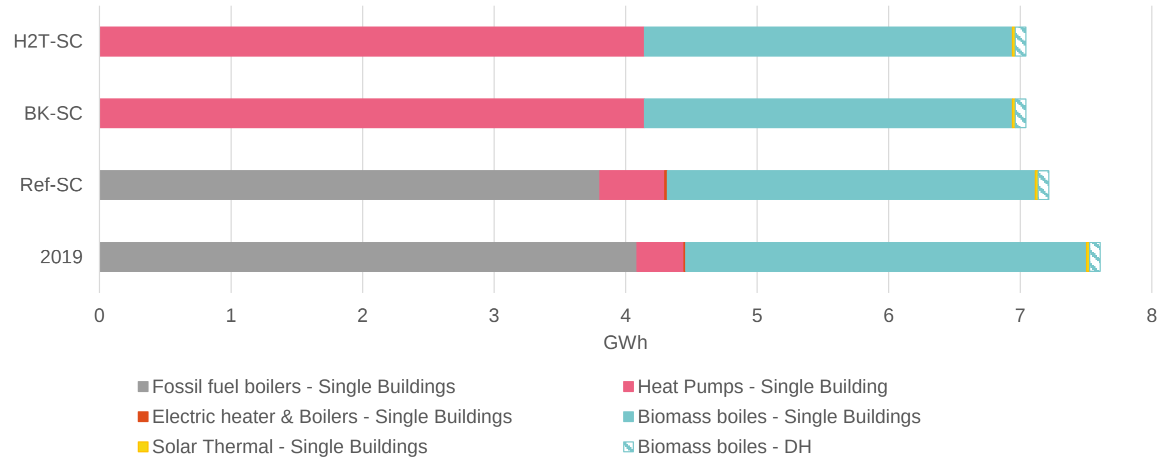

Figure 204: Comparison of the heat production by technology of the scenarios and base year in the village of Ollersdorf

6.6.3. Transport sector

Figure 205 presents the comparison of the energy consumption in the transport sector of the scenarios and the base year in the village of Ollersdorf. In the Ref-SC scenario there is an increase of 2% in the energy demand for transport sector with respect to the base year due to the increase of the population and a low penetration of EVs. However, in the BK-SC and the H2T-SC scenarios there is a high reduction of the energy demand because of the switch from ICE vehicles to EVs with a higher efficiency. The energy consumption in both scenarios is 2.75 GWh, which implies a 56% reduction compared to the base year.

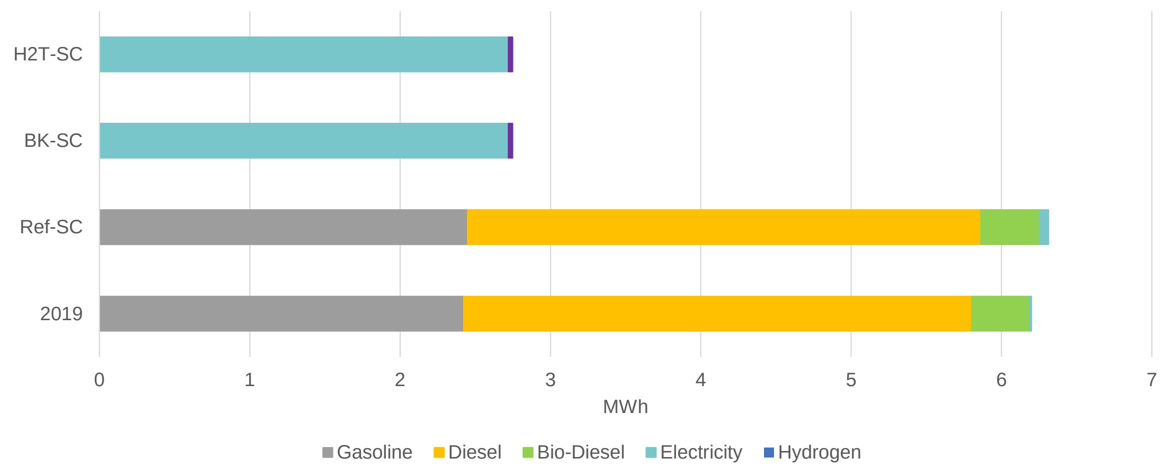

Figure 205: Comparison of the energy consumption in the transport sector of the scenarios and base year in the village of Ollersdorf

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6.6.4. Decarbonization

Figure 206 shows the comparison of the CO_2 emissions by sector of the scenarios and the base year in the village of Ollersdorf. In all the assessed scenarios there is a clear reduction of the overall CO_2 emissions compared to the base year, and the full decarbonization is achieved in the BK-SC and the H2T-SC scenarios. Indirect emissions due to the electricity imports from the national grid estimated at 100 tons of CO_2 by MWh in the base year, are phased out, because in 2030 the Austrian electric system will be carbon neutral (0 tons of CO_2 by MWh) in 2030 according with the Austrian NECP (European Commission, 2022). The Ref-SC scenario is the only scenario that has CO_2 emissions, with 3,028 tons of CO_2. This implies a reduction of 19% in the overall CO_2 emissions compared with the base year. The transport sector is the main emitting sector with overall direct CO_2 emissions of 1,553 tons of CO_2, followed by the residential sector with 765 tons of CO_2.

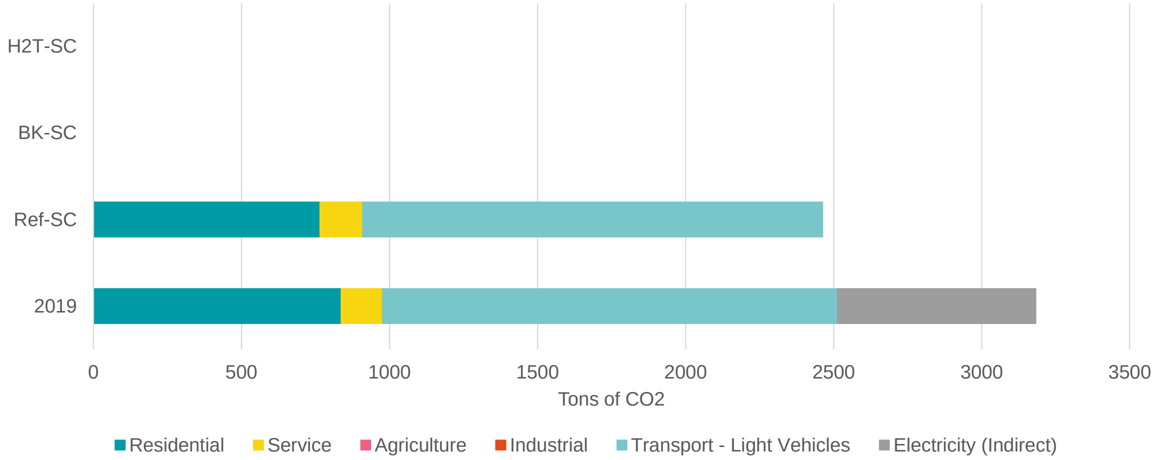

Figure 206: Comparison of the CO_2 emissions by sector of the scenarios and base year in Ollersdorf

6.7. Scale-up of the results - Thermenregion Stegersbach

This section includes the scale-up of results from the village of Ollersdorf to the Thermenregion Stegersbach, of which is part, to **assess the energy transformation in the region**. In particular, the results to be scaled up are the ones related to the Ref-SC, as they include the most feasible energy transformation.

The Stegersbach golf and spa region includes the seven political communities of Bocksdorf, Burgauberg-Neudauberg, Olbendorf, Ollersdorf, Rauchwart, Rohr and Stegersbach, located in southern Burgenland as shown in Figure 207. The region has around 91 km^2 and accounted for 7,968 residents in 2020, and it is shaped by tourism in relation to the use of thermal water. The region registers around 150,000 overnight stays every year. The planned regional model uses the existing strengths (tourism) and the great potential of the region (renewables, energy saving, e-mobility) to counteract the problems (dispersed settlement) and the risks (demographic development and aging) (Energie Kompass, 2019).

Figure 207: Thermenregion Stegersbach (Energie Kompass, 2019)

The specific data about energy consumption in the seven communities are limited and usually available at an aggregated level (Energie Kompass, 2019). In fact, as previously said, to estimate the breakdown of the energy consumption and demand for the village of Ollersdorf in the LocalRES project these sources were used, considering that there is specific information about energy consumption at community level that allows to know how the village of Ollersdorf performs with respect to the other communities and the region (Energie Mosaik, 2022).

Table 7 shows the energy share by sector in the Thermenregion Stegersbach, as well as the political communities. Results shows that Ollersdorf performs in a similar way as the overall Thermenregion Stegersbach regarding the distribution of energy consumption by sector (Energie Mosaik, 2022). In addition, economic and social dynamics related to the energy consumption of the seven communities are homogenous.

Table 7: Energy share by sector of Thermenregion Stegersbach (Energie Mosaik, 2022)

	Residential	Agriculture	Industry	Services	Transport
Bocksdorf	53%	5%	6%	8%	28%
Burgauberg-Neudauberg	44%	2%	24%	3%	26%
Olbendorf	54%	3%	7%	5%	31%
Ollersdorf	52%	2%	11%	5%	29%
Stegersbach	41%	1%	10%	15%	33%
Rohr im Burgenland	59%	8%	1%	3%	30%
Rauchwart	56%	13%	1%	4%	26%
Thermenregion Stegersbach	**47%**	**3%**	**11%**	**9%**	**30%**

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Considering that the villages belonging to the Thermenregion Stegersbach have similar boundary conditions, it is considered as possible scaling up directly the results of LocalRES project from the village of Ollersdorf to assess future demand and energy needs for the region based on a proportional rate. Thus, in Thermenregion Stegersbach the village of Ollersdorf constitutes a share of 11% of the energy consumption (Energie Mosaik, 2022), which is used to scale up the results of the Ref-SC.

The overall fuel demand for the Thermenregion Stegersbach is estimated in 235 GWh in 2030 (without distribution losses). **Residential sector is the largest energy sector** with a total fuel consumption of 85 GWh. Biomass is the main energy source with 29 GWh followed by natural gas with 23 GWh and fuel-oil with 11 GWh. Electricity consumption, mainly focussed on appliances, accounts for 20 GWh. The service sector accounts for 20 GWh of fuel consumption and electricity is the main source with 13 GWh, 65% of the overall fuel needs. **For the heating sector, natural gas and fuel-oil are the most relevant fuels** with 4 GWh and 2 GWh, respectively. Energy demand in the transport sector is 57 MWh and **around 127 EVs are expected to be in place** in 2030 with an electricity consumption of 0.5 GWh. However, **diesel and gasoline are the main fuels** accounting with 31 GWh and 22 GWh, respectively, and blended biodiesel covers the remaining needs.

The total electricity demand is estimated at 67 GWh (including electricity distribution losses) on an annual basis, where **electric appliances are the main electricity consumers** with 66 GWh. Electricity consumption for space heating (air-source HPs and geothermal HPs) accounts for 1 GWh of electricity, concentrating this demand during wintertime. DSM connected to this system shifts around 0.1 GWh of the electric demand.

PV is the main local electricity production system with an installed capacity of 63.6 MWp that generates 68 GWh of electricity (including transmission losses) to be able to achieve electric energy balance. In parallel, 1.1 MWh of **electric batteries are required to balance the electric system**. The transmission lines have enough capacity to allow a proper exchange of electricity between the region and the national grid, making **not necessary the use of batteries in a massive way as a flexibility option**.

The total heat production is estimated at 73 GWh (including distribution losses) on an annual basis. **Biomass boiler is the main technology** with 12 MW followed by natural gas with 10 MW and fuel-oil with 4.5 MW. These technologies produce 30 GWh, 25 MWh and 12 GWh of heat, respectively, which represent 91% of the overall heat production. The installed capacity of air-source HPs and ground HPs grows up to 0.4 MW and 1.5 MW, respectively, generating together 4.5 GWh of heat. **Thermal solar panels have a small contribution** with 0.2 GWh and thermal storage systems linked to this technology can balance around 0.05 GWh on an annual basis. The remaining marginal part is covered by other systems like electric heaters or coil boilers.

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6.8. Conclusions

Three scenarios are investigated under the LocalRES project for the village of Ollersdorf: Reference Scenario (Ref-SC), Blackout Scenario (BK-SC), Hydrogen in Transportation (H2T-SC). The goal of these scenarios is to define in the long-term perspective (2030) different possibilities about how a hypothetical energy community constituting the whole village can perform and support decarbonization of communities.

In general, the main conclusion is that **the village of Ollersdorf has enough PV potential to satisfy the expected future electricity demand** in terms of electric energy balance without bottlenecks in the transmission line which connects the village to the national grid. **The combination of PV and wind production is fundamental to achieve full electrification** of the current fossil fuel-based boilers as well as of the light vehicles sector. However, under this situation of full electrification **the transmission line capacity is not big enough to absorb all the electricity production surplus resulting in curtailment** of PV and wind production in certain moments and reducing the electricity exports.

To prevent the village of Ollersdorf against blackout events (BK-SC), the residual load approach implies that **there is need for a massive increase of electric batteries**. However, this supplementary capacity of electric batteries allows increasing the electricity balance and a more effective exchange with the national grid.

In case that the full electrification of the current fossil boilers takes place, **DSM has low impact on the modification of the overall electricity demand profile** as the electricity consumption by HPs is relatively low compared to the overall electricity consumption. Nevertheless, DSM produce a sequence of peaks and valleys in the heat profile. This is because COP of the HPs multiplies in the heat profile the impact of the variations of the DSM in the electricity profile.

Charging of EVs produces a saw-tooth in the overall electricity consumption profile. These peaks can be very intensive when a high number of EVs are connected to the grid. This is because three is enough supply electricity capacity and the smart charging concentrates the charging batteries in the moment of the day with the lowest electricity price. **The replacement of diesel-driven school buses by H_2-Buses represents a minor increase in the overall electricity demand** in the village and requires installing a small hydrogen system with an electrolyser linked to a hydrogen storage.

In terms of decarbonization, in all the assessed scenarios there is a clear reduction of the overall CO_2 emissions compared to the base year, and the full decarbonization is achieved in the BK-SC and H2T-SC. Indirect emissions are phased out in 2030 because the Austrian electric system will be carbon neutral. The Ref-SC scenario is the only one with CO_2 emissions, accounting for 3,028 tons of CO_2. This implies a reduction of 19% in the overall CO_2 emissions compared to the base year.

Finally, the results of LocalRES project from the village of Ollersdorf can be directly scaled up to assess the future demand and energy needs of the Thermenregion Stegersbach based on proportional rates, as this village performs in similar way as the overall region of which it is part.

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7/ Comparison of the project demos

In all pilots, the main actions to reduce direct emissions and support the local decarbonization were the electrification of the transport sector and the heating sector. In particular, the replacement of the ICE vehicles by EVs and of the individual fossil fuel boilers located in buildings by HPs were proposed. Additionally, the development of local renewables was also considered, mainly: PV in the village of Berchidda, wind in the island of Kökar, biomass CHP and PV in the village of Ispaster and PV combined with wind in the village of Ollersdorf. In the village of Ispaster, the local DH was also proposed to be expanded to cover the local heating needs. However, the high electrification of the demo can increase the indirect CO_2 emissions due the import from the national grid, as it happens in the village of Berchidda in the ELC-SC scenario.

The local production of H_2 to decarbonize the transport sector was also explored in the island of Kökar to replace the current diesel-powered ferry, and in the village of Ollersdorf to replace the school buses. In the island of Kökar, the high demand of electricity of the electrolyser to generate locally the H_2 for the Hydrogen-Powered ferry, combined with the requirement of ensuring an electricity balance, result in a high expansion of the local wind production compared to the case when hydrogen production is not necessary. However, the needs of H_2 production in the village of Ollersdorf are estimated to be much lower, only resulting in a small increase of the local wind capacity compared to the case when there is no hydrogen production, even though ensuring an electricity balance is also a requirement in this case.

In the villages of Ollersdorf, Berchidda and Ispaster, a high increase of batteries is needed to protect them against blackout events. The batteries are used to trade electricity with their national grids, charging batteries when the national prices are lower, and exporting the electricity when the prices are higher. This mechanism allows these communities to potentially provide additional services to the grid operators and increase their revenues.

In the case of Berchidda and Ispaster, the reduction of their effective capacity in terms of transmission line connecting the villages to the national grids were considered. In both cases, the flexibility measures contribute to achieve this objective. However, this reduction was lower in the village of Ispaster because the effective capacity of the transmission line was already low.

The protection against blackout events was addressed in all the pilots except in the island of Kökar. The most critical blackout event was selected based on the residual load. In the village of Berchidda, the technical limitation of the maximum technical capacity for electric batteries made necessary to propose disconnecting other devices to be able to provide enough electricity to maintain running the critical infrastructure; i.e., one third of the total needs. In the villages of Ollersdorf and Ispaster, this limitation was not considered, therefore in these cases all the electric load could be covered during the blackout event.

In the island of Kökar and in the village of Ollersdorf, achieving an electricity energy balance was addressed. In Kökar, the wind electricity production was identified as a key element, being the main electricity source to achieve this objective. The use of PV is minor due to the low FLH in the island.

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In Ollersdorf, the local PV production can achieve the objective of the electricity balance as soon as the future electricity demand does not experiment a high increase compared to the current situation. However, a high electrification of the heating sector and transport sector would imply the inclusion of wind production in the village to achieve this objective.

The electrification of the heating and transport sectors of the communities can produce high mismatches between electricity demand and production. In the village of Berchidda, the full electrification of the heating sector resulted in a high change in the electricity curve load between winter and summer periods, being this change much higher during wintertime. Nevertheless, local electricity production was mainly in summer, as PV was the only source. This was similar in the case of the village of Ollersdorf, when only PV was considered in its local electricity mix. This effect was mitigated in Ollersdorf when wind was also considered. In the same way, in the island of Kökar this situation was mitigated as wind was the predominant technology in the island. In the village of Ispaster, this effect was also mitigated using a biomass CHP system, which allows producing electricity with independence of the weather conditions.

In Berchidda, Ollersdorf and Kökar, in cases of a high mismatch between electricity demand and local electricity production a situation of curtailment can occur. This happens in certain periods when the surplus of electricity from local sources cannot be totally absorbed by the load, stored in the batteries or exported to the national grid. In the village of Berchidda, these periods are estimated to potentially take place during the summertime due to the high PV production. In the village of Ollersdorf and in the island of Kökar, the situations of curtailment are associated to the high capacity of wind production resulting from trying to keep the electricity energy balance, because in certain moments high peaks of electricity production take place.

Flexibility measures were explored in all the demos, and it was proved that these mechanisms can support the local communities to be more sustainable, reduce their direct and indirect CO_2 emissions and their dependence from the national grid, and be prepared against blackout events. Berchidda and Ispaster are the demos where the electric transmission line with the national grid is "weaker", which allows the flexibility measures to be more active and support more the community energy system. In this sense, smart charging for EVs was proven as an effective measure. Moreover, in the village of Berchidda the use of V2G showed that this system can additionally support providing additional storage capacity to balance the local grid, especially in cases with a high penetration of EVs.

Only in the village of Ispaster the possibility to work as an energy island was explored, implying a full disconnection from the national grid. This scenario resulted in a biomass CHP system being necessary at local level to produce electricity independently from the weather conditions, to be able to compensate the variability of PV production when flexibility options are not enough.

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8/ Overall conclusions

Three scenarios have been analysed within the LocalRES project in each pilot. The goal of these scenarios is to define different possibilities in the long-term perspective (2030) about how the established energy community can perform and support decarbonization in the village. In this analysis, the impact of flexibility measures such as demand side management (DSM), smart charging for EVs, energy storage, as well as the use of HPs, CHP, local VRESs, hydrogen production, blackout prevention, and reduction of the dependence grid are explored.

The assessment of the scenarios was done with Balmorel modelling tool. This modelling tool is an open-source modelling tool for optimizing energy production investments in different scenarios. It is a model that minimizes the total investment and operational costs of the systems allowing to find the least-cost solution for the energy transformation in each scenario.

In general, the proposed scenarios for potential energy communities in the different demos can support the decarbonization of the community due to a more efficient use of the local energy resources supported by flexibility measured to properly address the higher electrification of the system.

The replacement of the fossil fuel boilers and ICE vehicles by electricity-driven systems (e.g. HPs and EVs) can support the reduction of the direct local CO_2 emissions. However, an increase of the electrification can also cause a rebound effect, increasing indirect CO_2 emissions due to the higher electricity imports from the national grid. In this sense, it is important accompanying the policy of increasing the use of electric equipment (e.g., HPs, EVs) together with additional renewable capacity to mitigate the possible increase of indirect CO_2 emissions.

Achieving an electric energy balance in the community can reduce the indirect CO_2 emission, especially in cases when the national grid has a high emission intensity associated to the electricity production. In case that the national grid is already decarbonized, there is not impact on the reduction of the indirect CO_2 emission due to the local increase of renewable sources.

Flexibility measures as the DSM, smart-charging or the use of storage allow reducing the needs of the effective capacity of the transmission line significant way e.g., in the village of Berchidda 15% and in the village of Ispaster 7%. This allows the community to be more resilient to the possible lack of power from the transmission line, and even to use this flexibility to provide services to the electric system operator. Nevertheless, there are limitations for the flexibility measures making necessary to increase the transmission line capacity in case there is high growth of the electricity demand, together with the impossibility to expand local electricity production capacity

PV is the most relevant technology for electricity production; however, wind production can play an important role in the communities where solar radiation is low or in case that PV installed capacity achieves its maximum potential. The advantages of the wind production over PV are the higher number of FLH and lower seasonal dependence in the electricity production.

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A seasonal mismatch can occur between local production and consumption. In this sense, PV panels have the higher electricity production in summer, but the higher electricity demand can happen in winter, especially when the heating sector is electrified. This situation can produce curtailment in these systems during the summertime because the electricity surplus generated from PV could not be consumed, exported to the national grid or stored.

Enough capacity of the transmission line between the energy community to the main national grid to ensure electricity trading is fundamental to achieve the electric energy balance of the community. Low capacity in combination with a high demand can produce an overcapacity of local vRES as well as curtailment to achieve electric energy balance.

Preventing the communities against blackouts from the transmission line implies a high increase of electric batteries. This additional capacity of electric batteries not only mitigate the blackout event, but can also increase the electricity balance and get a more effective electricity exchange with the national grid to generate revenues to the community. However, limitations in the potential in the installation of these systems causes that electricity demand can be covered only partially in the moment of blackout. This makes necessary reducing the load by disconnecting electric devices from the electric network to be able to satisfy the critical systems; e.g., hospitals.

A high proportion of electric heating system produces a significant growth in the electricity demand during wintertime and a high imbalance between this period and summertime. In addition, DSM can produce high fluctuations in the heating profiles due to the high penetration of HPs in the heating sector in combination of a multiplier effect from the COP of these heating technologies.

Smart-charging or V2G is an affective flexibility measure to adopt the overall electricity consumption of the village to reduce the impact on the lack of power of the grid and reduce the charging cost. However, this control system can produce a saw-tooth effect in the overall electricity consumption profile. These peaks can be very intensive when a high number of EVs are connected to the grid.

Base load electricity production, and in particular biomass CHP, can be very relevant and fundamental to achieve the full independence from the national grid of an energy community (energy island). However, this technology must have a high CHP ratio to be able to cover the new electricity needs. In these energy communities, this technology can be relevant especially during the wintertime. However, it can be combined with PV panels during the summer period. In this context, energy storage would take a fundamental role to balance electricity and heat.

The location of the infrastructure to generate hydrogen to decarbonize transport modes in the regular transport routes (e.g., ferry routes and scholar bus routes) has a relevant impact on the electricity consumption and production. This infrastructure can make grow exponentially the electricity demand in the communities in case of relevant hydrogen needs (e.g., ferry). The hydrogen infrastructure can combine an electrolyser and a hydrogen storage. In this case, the most effective way to operate the electrolyser located in the village is as a constant load and using the H_2 storage to balance the H_2 supply.

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9/ ANNEX A. Data for the scenarios of the demo sites

Table 8: Demand scenarios, technology capacity, energy production and exchange and CO_2 emissions of the scenarios in Kökar demo case

	2017	Ref-SC	EB-SC	TD-SC
DEMAND SCENARIOS		DMD-Ref	DMD-Ref	DMD-TD
INSTALLED CAPACITY				
Electricity capacity [kW, kWh Storage]				
Transmission line	1,500	1,500	3,000	3,000
PV panels	49	74	74	74
Wind turbines	530	795	1,122	9,440
Electric batteries	-	-	-	-
Heating capacity - Individual Systems in Buildings [kW, kWh Storage]				
Solar thermal panels	-	-	-	-
Thermal storage	-	-	-	-
Air-source HP	88	249	249	249
Geothermal Heat-Pump	293	299	299	299
Electric Boiler (DHW)	-	-	-	-
Electric Heater (Space Heating)	-	-	-	-
Natural Gas Boiler	-	-	-	-
Fuel-Oil Boiler	172	-	-	-
Liquid Petroleum Gases - Boiler	-	-	-	
Biomass Boiler	359	355	355	355
Coal boilers	-	-	-	-
Heating capacity - DH [kW, kWh Storage]				
Solar thermal panels	-	-	-	-
Thermal Storage	-	-	-	-
Biomass Boiler	-	-	-	-
Biomass CHP	-	-	-	-
Geothermal HP	-	-	-	-
Gas Boiler	-	-	-	-
Hydrogen capacity [kW, kWh Storage]				
PEMEC Electrolyser	-	-	-	2,320
H_2 Storage	-	-	-	19,137
ENERGY PRODUCTION				
Local electricity production & Import-Export [MWh]				
PV panels	38	56	56	56
Wind turbines	1,523	2,278	3,216	23,467
Biomass CHP	-	-	-	-
Import	1,396	1,559	1,307	8,385
Export		621	1,307	8,385
Local heat production - Individual Systems in Buildings [MWh]				
Solar thermal panels	-	-	-	-
Air-source HP	278	760	760	760

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Geothermal HP	902	913	913	913
Electric Boiler (DHW)	-	-	-	-
Electric Heater (Space Heating)	-	-	-	-
Natural Gas Boiler	-	-	-	-
Fuel-Oil Boiler	475	-	-	-
Liquid Petroleum Gases - Boiler	-	-	-	-
Biomass Boiler	949	937	937	937
Coal boilers	-	-	-	-
Local heat production - DH [MWh]				
Solar thermal panels	-	-	-	-
Biomass Boiler	-	-	-	-
Biomass CHP	-	-	-	-
Geothermal Heat-Pump	-	-	-	-
Gas Boiler	-	-	-	-
Local hydrogen production [MWh]				
PEMEC Electrolyser	-	-	-	14,854
FLEXIBILITY MEASURES				
Flexibility measures [MWh]				
Demand Side Management	-	15	24	34
Grid2V	-	22	22	217
V2G	-	-	-	-
Electric batteries	-	-	-	-
Heat Storage-Individual Sys. Buildings	-	-	-	-
Heat Storage - DH	-	-	-	-
H_2 Storage	-	-	-	12,367
CO_2 EMISSIONS				
CO_2 emissions [tons of CO_2)				
Residential	64	-	-	-
Service	80	-	-	-
Agriculture	-	-	-	-
Industrial	-	-	-	-
Transport	2,750	2,679	2,679	389
Electricity (Indirect)	95	64	-	-

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Table 9: Demand scenarios, technology capacity, energy production and exchange and CO_2 emissions of the scenarios in Berchidda demo case

	2017	Ref-SC	BK-SC	ELC-SC
DEMAND SCENARIOS		DMD-Ref	DMD-Ref	DMD-ELC
INSTALLED CAPACITY				
Electricity capacity [kW, kWh Storage]				
Transmission line	1,500	1,500	1,275	2,100
PV panels	608	2,108	2,108	2,108
Wind turbines	-	-	-	-
Electric batteries	-	400	997	1,000
Heating capacity - Individual Systems in Buildings [kW, kWh Storage]				
Solar thermal panels	57	52	52	52
Thermal storage	281	260	260	1,548
Air-source HP	-	1,390	1,454	6,031
Geothermal HP	-	-	-	-
Electric Boiler (DHW)	211	182	182	-
Electric Heater (Space Heating)	809	391	373	-
Natural Gas Boiler	-	-	-	-
Fuel-Oil Boiler	1,008	458	458	-
Liquid Petroleum Gases - Boiler	1,174	532	532	-
Biomass Boiler	3,254	2,952	2,952	-
Coal Boiler	-	-	-	-
Heating capacity - DH [kW, kWh Storage]				
Solar thermal panels	-	-	-	-
Thermal Storage	-	-	-	-
Biomass Boiler	-	-	-	-
Biomass CHP	-	-	-	-
Geothermal HP	-	-	-	-
Gas Boiler	-	-	-	-
Hydrogen capacity [kW, kWh Storage]				
PEMEC Electrolyser	-	-	-	-
H_2 Storage	-	-	-	-
ENERGY PRODUCTION				
Local electricity production & Import-Export [MWh]				
PV panels	821	2,642	2,648	2,683
Wind turbines	-	-	-	-
Biomass CHP	-	-	-	-
Import	4,941	4,352	4,320	7,128
Export	-	773	711	766
Local heat production - Individual Systems in Buildings [MWh]				
Solar thermal panels	77	71	71	71
Air-source HP	-	2,575	2,583	11,755
Geothermal HP	-	-	-	-
Electric Boiler (DHW)	1,402	1,283	1,283	-
Electric Heater (Space Heating)	1,448	670	668	-

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Natural Gas Boiler	-	-	-	-
Fuel-Oil Boiler	1,954	889	889	-
Liquid Petroleum Gases - Boiler	3,028	1,367	1,367	-
Biomass Boiler	5,868	5,323	5,323	-
Coal boiler	-	-	-	-
Local heat production - DH [MWh]				
Solar thermal panels	-	-	-	-
Biomass Boiler	-	-	-	-
Biomass CHP	-	-	-	-
Geothermal Heat-Pump	-	-	-	-
Gas Boiler	-	-	-	-
Local hydrogen production [MWh]				
PEMEC Electrolyser	-	-	-	-
FLEXIBILITY MEASURES				
Flexibility measures [MWh]				
Demand Side Management	-	87	77	191
Grid2V	-	171	171	2,251
V2G	-	-	-	389
Electric batteries	-	128	327	313
Heat Storage-Individual Sys. Buildings	-	59	59	119
Heat Storage - DH	-	-	-	-
H_2 Storage	-	-	-	-
CO_2 EMISSIONS				
CO_2 emissions [tons of CO_2)				
Residential	1,162	526	526	-
Service	191	87	87	-
Agriculture	-	-	-	-
Industrial	-	-	-	-
Transport	1,194	983	983	-
Electricity (Indirect)	1,225	879	886	1,562

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Table 10: Demand scenarios, technology capacity, energy production and exchange and CO_2 emissions of the scenarios in Ispaster demo case

	2019	Ref-SC	BK-SC	EI-SC
DEMAND SCENARIOS		DMD-Ref	DMD-Ref	DMD-EI
INSTALLED CAPACITY				
Electricity capacity [kW, kWh Storage]				
Transmission line	112	112	104	-
PV panels	28	410	647	534
Wind turbines	-	-	-	-
Electric batteries	178	413	880	1,068
Heating capacity - Individual Systems in Buildings [kW, kWh Storage]				
Solar thermal panels	4	13	13	25
Thermal storage	29	25	25	13
Air-source HP	-	43	43	116
Geothermal HP	-	-	-	-
Electric Boiler (DHW)	-	-	-	-
Electric Heater (Space Heating)	-	-	-	-
Natural Gas Boiler	-	-	-	-
Fuel-Oil Boiler	14	2	2	-
Liquid Petroleum Gases - Boiler	309	61	61	-
Biomass Boiler	79	8	8	-
Coal boilers	-	-	-	-
Heating capacity - DH [kW, kWh Storage]				
Solar thermal panels	42	42	42	42
Thermal Storage	300	178	178	178
Biomass Boiler	220	255	281	336
Biomass CHP	-	H55/E5	H55/E5	H540/E180
Geothermal Heat-Pump	-	30	30	
Gas Boiler	130	-	-	-
Hydrogen capacity [kW, kWh Storage]				
PEMEC Electrolyser	-	-	-	-
H_2 Storage	-	-	-	-
ENERGY PRODUCTION				
Local electricity production & Import-Export [MWh]				
PV panels	30	525	768	654
Wind turbines	-	-	-	-
Biomass CHP	-	39	39	817
Import	693	612	510	-
Export	-	151	268	-
Local heat production - Individual Systems in Buildings [MWh]				
Solar thermal panels	6	19	19	19
Air-source HP	-	124	124	328
Geothermal HP	-	-	-	-
Electric Boiler (DHW)	-	-	-	-
Electric Heater (Space Heating)	-	-	-	-

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Natural Gas Boiler	-	-	-	-
Fuel-Oil Boiler	36	7	7	-
Liquid Petroleum Gases - Boiler	868	175	175	-
Biomass Boiler	118	21	21	-
Coal boilers	-	-	-	-
Local heat production - DH [MWh]				
Solar thermal panels	44	53	53	53
Biomass Boiler[10]	115	431	431	105
Biomass CHP	-	434	429	947
Geothermal Heat-Pump	-	185	189	-
Gas Boiler	3	-	-	-
Local hydrogen production [MWh]				
PEMEC Electrolyser	-	-	-	-
FLEXIBILITY MEASURES				
Flexibility measures [MWh]				
Demand Side Management	-	3	3	4
Grid2V	-	121	121	549
V2G	-	-	-	0
Electric batteries	-	201	328	187
Heat Storage-Individual Sys. Buildings		3	3	3
Heat Storage - DH	-	20	20	51
H_2 Storage	-	-	-	-
CO_2 EMISSIONS				
CO_2 emissions [tons of CO_2)				
Residential	194	35	35	0
Service	30	10	10	0
Agriculture	3	3	3	0
Industrial	0	0	0	0
Transport	409	357	357	0
DH	1	0	0	0
Electricity (Indirect)	182	28	15	0

[10] This value is estimated to achieve energy balance in the DH

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Table 11: Demand scenario, technology capacity, energy production and exchange and CO_2 emissions of the scenario in Ollersdorf demo case

	2017	Ref-SC	BK-SC	H2T-SC
DEMAND SCENARIOS		DMD-Ref	DMD-ELC	DMD-ELC
INSTALLED CAPACITY				
Electricity capacity [kW, kWh Storage]				
Transmission line	5,000	5,000	5,000	5,000
PV panels	317	7,097	7,097	7,097
Wind turbines	-	-	3,153	3,181
Electric batteries	38	121	8,172	8,256
Heating capacity - Individual Systems in Buildings [kW, kWh Storage]				
Solar thermal panels	18	16	16	16
Thermal storage	53	53	76	76
Air-source HP	28	38	1,449	1,449
Geothermal HP	113	151	150	150
Electric Boiler (DHW)	2	3	-	-
Electric Heater (Space Heating)	-	-	-	-
Natural Gas Boiler	1,037	961	-	-
Fuel-Oil Boiler	509	471	-	-
Liquid Petroleum Gases - Boiler	-	-	-	-
Biomass Boiler	1,285	1,172	1,172	1,172
Coal boilers	4	4	-	-
Heating capacity - DH [kW, kWh Storage]				
Solar thermal panels	-	-	-	-
Thermal Storage	-	-	-	-
Biomass Boiler	30	30	30	30
Biomass CHP	-	-	-	-
Geothermal Heat-Pump	-	-	-	-
Gas Boiler	-	-	-	-
Hydrogen capacity [kW, kWh Storage]				
PEMEC Electrolyser	-	-	-	8
H_2 Storage	-	-	-	112
ENERGY PRODUCTION				
Local electricity production & Import-Export [MWh]				
PV panels	333	7,431	7,431	7,431
Wind turbines	-	-	-	-
Biomass CHP	-	-	-	-
Import	6,692	3,758	6,211	6,222
Export	-	3,758	6,211	6,222
Local heat production - Individual Systems in Buildings [MWh]				
Solar thermal panels	23	23	23	23
Air-source HP	72	99	3,750	3,750
Geothermal HP	285	394	393	393
Electric Boiler (DHW)	14	21	-	-
Electric Heater (Space Heating)	-	-	-	-

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Natural Gas Boiler	2,811	2,619	-	-
Fuel-Oil Boiler	1,265	1,176	-	-
Liquid Petroleum Gases - Boiler	-	-	-	-
Biomass Boiler	3,047	2,797	2,797	2,797
Coal boiler	10	9	-	-
Local heat production - DH [MWh]				
Solar thermal panels	-	-	-	-
Biomass Boiler	81	81	81	81
Biomass CHP	-	-	-	-
Geothermal Heat-Pump	-	-	-	-
Gas Boiler	-	-	-	-
Local hydrogen production [MWh]				
PEMEC Electrolyser	-	-	-	28
FLEXIBILITY MEASURES				
Flexibility measures [MWh]				
Demand Side Management	-	-	-	63
Grid2V	-	-	-	2,695
V2G	-	-	-	-
Electric batteries	-	-	-	2,383
Heat Storage-Individual Sys. Buildings	-	-	-	12
Heat Storage - DH	-	-	-	-
H_2 Storage	-	-	-	26
CO_2 EMISSIONS				
CO_2 emissions [tons of CO_2)				
Residential	837	765	-	-
Service	140	144	-	-
Agriculture	6	6	-	-
Industrial	560	560	-	-
Transport	1,537	1,553	-	-
Electricity (Indirect)	669	-	-	-

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10/ ANNEX A. Fuel use for the demand scenarios

Table 12: Values for the demand scenarios of Kökar demo case

	Base Year								DMD-Ref								DMD-TD							
[MWh]	Residential	Service	Agriculture	Industry	Light Vehicles	Transport - Others	Boats	Ferry	Residential	Service	Agriculture	Industry	Light Vehicles	Transport - Others	Boats	Ferry	Residential	Service	Agriculture	Industry	Light Vehicles	Transport - Others	Boats	Ferry
Total	**2,962**	**2,561**	**-**	**-**	**546**	**394**	**2,165**	**7,250**	**2,917**	**2,525**	**-**	**-**	**513**	**394**	**2,009**	**7,250**	**2,917**	**2,525**	**-**	**-**	**219**	**394**	**1,383**	**14,895**
Coal	-	-	-	-	-	-	-	-	-	-	-	-					-	-	-	-				
Gasoline	-	-	-	-	499	393	1,222	-	-	-	-	-	453	393	1,100	-	-	-	-	-	-	393	611	-
Diesel	-	-	-	-	46	-	943	7,250	-	-	-	-	38	-	849	7,250	-	-	-	-	-	-	472	-
Fuel Oil	240	300	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
Hydrogen	-	-	-	-					-	-	-	-	-	-	-	-	-	-	-	-				14,895
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LPG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	1,066	64	-	-	-	-	-	-	1,053	64	-	-	-	-	-	-	1,053	64	-	-	-	-	-	-
Biodiesel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ambient heat from Air-HP	36	163	-	-	-	-	-	-	184	351	-	-	-	-	-	-	184	351	-	-	-	-	-	-
Ground heat from Geo-HP	54	648	-	-	-	-	-	-	53	648	-	-	-	-	-	-	53	648	-	-	-	-	-	-
Solar Thermal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-					-	-	-	-
Electrical Devices	1,537	1,137	-	-	-	-	-	-	1,537	1,137	-	-	-	-	-	-	1,537	1,137	-	-	-	-	-	-
Electricity Air-HP	14	65	-	-	-	-	-	-	74	140	-	-	-	-	-	-	74	140	-	-	-	-	-	-
Electricity Geothermal-HP	15	185	-	-	-	-	-	-	15	185	-	-	-	-	-	-	15	185	-	-	-	-	-	-
Electricity EH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electricity EVs	-	-	-	-	1	1	-	-	-	-	-	-	22	1	60	-	-	-	-	-	219	1	301	-

Table 13: Values for the demand scenarios of Berchidda demo case

	Base Year					DMD-Ref					DMD-ELC				
[MWh]	Residential	Service	Agriculture	Industry	Light Vehicles	Residential	Service	Agriculture	Industry	Light Vehicles	Residential	Service	Agriculture	Industry	Light Vehicles
Total	**17,235**	**3,707**	**-**	**369**	**4,514**	**15,479**	**3,430**	**-**	**369**	**3,889**	**11,554**	**3,374**	**-**	**369**	**1,729**
Coal	-	-	-	-	-	-	-	-	-		-	-	-	-	
Gasoline	-	-	-	-	2,465	-	-	-	-	2,029	-	-	-	-	-
Diesel	-	-	-	-	2,049	-	-	-	-	1,687	-	-	-	-	-
Fuel Oil	1,899	305	-	-	-	862	141	-	-		-	-	-	-	
Hydrogen	-	-	-	-		-	-	-	-		-	-	-	-	
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LPG	2,783	464	-	-	-	1,258	208	-	-		-	-	-	-	
Biomass	9,955	66	-	-	-	9,029	61	-	-		-	-	-	-	
Biodiesel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ambient heat from Air-HP	-	-	-	-	-	1,143	685	-	-	-	6,813	1,543	-	-	-
Ground heat from Geo-HP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solar Thermal	38	40	-	-	-	34	36	-	-	-	34	36	-	-	-
DH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrical Devices	1,397	1,061	-	369	-	1,278	1023	-	369	-	1,278	1,023	-	369	-
Electricity Air-HP	-	-	-	-	-	457	274	-	-	-	2,725	617	-	-	-
Electricity Geothermal-HP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electricity EH	1,164	1,771	-	-	-	1,417	1,002	-	-	-	704	155	-	-	-
Electricity EVs	-	-	-	-	-	-	-	-	-	173	-	-	-	-	1,729

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Table 14: Values for the demand scenarios of Ispaster demo case

[MWh]	Base Year						DMD-Ref						DMD-EI					
	Residential	Service	Agriculture	Industry	Light Vehicles	Transport - Others	Residential	Service	Agriculture	Industry	Light Vehicles	Transport - Others	Residential	Service	Agriculture	Industry	Light Vehicles	Transport - Others
Total	**1,447**	**378**	**48**	**114**	**1,207**	**335**	**1,510**	**396**	**48**	**114**	**1,131**	**335**	**1,499**	**395**	**48**	**114**	**554**	**335**
Coal	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-
Gasoline	-	-	-	-	382	-	-	-	-	-	335	-	-	-	-	-	-	-
Diesel	-	-	-	-	825	335	-	-	-	-	674	335	-	-	-	-	-	-
Fuel Oil	37	4	11	-	-	-	7	1	11	-	-	-	-	-	-	-	-	-
Hydrogen	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LPG	780	124	-	-	-	-	143	40	-	-	-	-	-	-	-	-	-	-
Biomass	140	-	-	-	-	-	26	-	-	-	-	-	-	-	-	-	-	-
Biodiesel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	-	-	335
Ambient heat from Air-HP	-	-	-	-	-	-	73	16	-	-	-	-	190	44	-	-	-	-
Ground heat from Geo-HP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solar Thermal	6	-	-	-	-	-	19	-	-	-	-	-	19	-	-	-	-	-
DH	72	90	-	-	-	-	773	166	-	-	-	-	773	166	-	-	-	-
Electrical Devices	412	160	37	114	-	-	441	168	37	114	-	-	441	168	37	114	-	-
Electricity Air-HP	-	-	-	-	-	-	29	6	-	-	-	-	76	17	-	-	-	-
Electricity Geothermal-HP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electricity EH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
Electricity EVs	-	-	-	-	-	-	-	-	-	-	122	-	-	-	-	-	554	-

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Table 15: Values for the demand scenarios of Ollersdorf demo case[11]

[MWh]	Base Year						DMD-Ref						DMD-ELC					
	Residential	Service	Agriculture	Industry	Light Vehicles	H_2 Buses	Residential	Service	Agriculture	Industry	Light Vehicles	H_2 Buses	Residential	Service	Agriculture	Industry	Light Vehicles	H_2 Buses
Total	**9,809**	**2,100**	**300**	**7,700**	**6,200**	**-**	**9,377**	**2,161**	**300**	**7,700**	**6,314**	**-**	**9,147**	**2,119**	**304**	**8,080**	**2,720**	**28**
Coal	12	-	1	11	-	-	11	-	1	11		-	-	-	-	-		-
Gasoline	-	-	-	-	2,423	-	-	-	-	-	2,448	-	-	-	-	-	-	-
Diesel	-	-	-	-	3,380	-	-	-	-	-	3,415	-	-	-	-	-	-	-
Fuel Oil	1,243	194	3	101	-	-	1,137	200	3	101	-	-	-	-	-	-		-
Hydrogen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		28
Natural Gas	2,490	438	24	2,630	-	-	2,277	451	24	2630	-	-	-	-	-	-	-	
LPG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	3,528	100	171	1,560	-	-	3,227	103	171	1,560	-	-	3,227	103	203	4,681	-	-
Biodiesel	-	-	-	-	388	-	-	-	-	-	392	-	-	-	-	-	-	-
Ambient heat from Air-HP	53	-	-	-	-	-	70	-	-	-	-	-	2,368	434	-	-	-	-
Ground heat from Geo-HP	229	-	-	-	-	-	306	-	-	-	-	-	306	-	-	-	-	-
Solar Thermal	23	-	-	-	-	-	23	-	-	-	-	-	23	-	-	-	-	-
DH	85	-	-	-	-	-	85	-	-	-	-	-	85	-	-	-	-	-
Electrical Devices	2,046	1,368	101	3,399	-	-	2,105	1,408	101	3,399	-	-	2,105	1,408	101	3,399	-	-
Electricity Air-HP	21	-	-	-	-	-	28	-	-	-	-	-	947	174	-	-	-	-
Electricity Geothermal-HP	65	-	-	-	-	-	87	-	-	-	-	-	87	-	-	-	-	-
Electricity EH	14	-	-	-	-	-	21	-	-	-	-	-	-	-	-	-	-	-
Electricity EVs	-	-	-	-	10	-	-	-	-	-	59	-	-	-	-	-	2,720	-

[11] The 28 MWh of hydrogen in the DMD-ELC scenario is only considered in the H2T-SC scenario

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